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LECTURES

ON

AGRICULTURAL CHEMISTRY.

2 vol. in 3 pts.

LECTURES

ON

AGRICULTURAL CHEMISTRY

AND

GEOLOGY.

"*The profit of the earth is for all; the King himself is served by the field.*"
ECCLES. V. 9.

BY

JAS. F. W. JOHNSTON, M. A., F. R. SS. L. & E.

FELLOW OF THE GEOLOGICAL SOCIETY, ETC., ETC.

READER OF CHEMISTRY AND MINERALOGY IN THE UNIVERSITY OF DURHAM.

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PREFACE.

The following Lectures were addressed to a Society* of practical agriculturists, many of whom possessed no knowledge whatever of scientific Chemistry or Geology. They commence, therefore, with the discussion of those elementary principles which are necessary to a proper understanding of each branch of the subject. Every thing in such Lectures, which is not—or may not be—easily understood by those to whom they are addressed, is worse than useless. It is my intention, therefore, to employ no scientific terms, and to refer to no philosophical principles, which I have not previously explained. Having been requested to publish these Lectures for the benefit of practical agriculturists in general, I have endeavoured to adapt them to the average knowledge of that class. To many who may take up the later Lectures, some points may appear obscure or difficult to be fully understood; such persons will, I hope, do me the justice to begin at the beginning, and to blame the author only when that which is necessary to the understanding of the later, is not to be found in the earlier Lectures.

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* The Durham County Agricultural Society, and the Members of the Durham Farmers' Club.

Those who possess a certain amount of chemical knowledge will derive much benefit from a perusal of Liebig's "Organic Chemistry, in its applications to Agriculture and Physiology;" and from "Three Lectures on Agriculture," by Professor Daubeny, of Oxford.

For the sake of clearness, I have, in the following pages divided the subject into *four* parts, the study of each preceding part preparing the way for a complete understanding of those which follow. Thus the first part is devoted to the *organic elements* and parts of plants, the nature and sources of these elements, and an explanation of the mode in which they become converted into the substance of plants—the second to the *inorganic elements* of plants, comprehending the study of the soils from which these elements are derived—with the general relations of geology to agriculture—the third to the *nature of manures*, by which soils are made more productive, and the amount of vegetable produce increased—and the fourth, to the *results of vegetation*—to the kind and value of the food produced under different circumstances—and its relation to the growth of cattle, and to the amount and quality of dairy produce.

By this method I have endeavoured to ascend from the easy to the apparently difficult; and I trust that the willing and attentive reader will find no difficulty in keeping by my side during the entire ascent.

Durham, 1841.

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ERRATA.

Part II. p. 311, lines 1 and 2, for *first* read *second*, and for *second* read *first* oxide.

Part III. p. 177, line 1, for XVIII read XVI.
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LECTURES ON THE APPLICATIONS OF CHEMISTRY AND GEOLOGY TO AGRICULTURE.

Part I.

ON THE ORGANIC ELEMENTS OF PLANTS.

LECTURE I.

Importance of Agriculture—Relation of the growth of food to the population of Great Britain—Recent progress and prospects of English Agriculture—Application of Chemical and Geological Science to the art of culture—to the improvement of soils—the rotation of crops—the application of manures, &c.—Outline of the Course of Lectures—Number and nature of the elementary bodies—The organic elements Carbon, Hydrogen, Oxygen, and Nitrogen, their properties and their relations to vegetable life.

Were I about to address you in a single or detached Lecture only, I should think it my duty to select some one branch of the art of culture for special illustration, and without much introductory matter to proceed at once to the exposition of the principle or principles on which it depended. As the present, however, is only the first of a Series of Lectures I hope to have the honor of delivering to you, I may be permitted to introduce my subject with a few prefatory remarks, which will here find their appropriate place.

In regard to the importance of Agriculture it may appear superfluous in me to address you. That art on which a thousand millions of men are dependent for their very sustenance—in the prosecution of which nine-tenths of the fixed capital of all civilized nations is embarked—and probably two hundred millions of men expend their daily toil—that art must confessedly be the most important of all; the parent and precursor of all other arts. In every country then, and at every period, the investigation of the principles on which the rational practice of this art is founded, ought to have commanded the principal attention of the greatest minds. To what other object could they have been more beneficially directed?

But there are periods in the history of every country when the study of Agriculture becomes more urgent, and in that country acquires a vastly superior importance. When a tract of land is thinly peopled, like the newly settled districts of North America, New Holland, or New Zealand, a very defective system of culture will produce food enough not only for the wants of the inhabitants, but for the partial supply of other countries also. But when the population becomes more dense, the same imperfect or sluggish system will no longer suffice. The land must be better tilled, its special qualities and defects must be studied, and means must gradually be adopted for extracting the maximum produce from every portion susceptible of cultivation.

The British islands are in this latter condition. Agriculture now is of vastly more importance to us as a nation, than it was towards the close even of the last century. In 1780, the island of Great Britain contained about 9 millions of inhabitants; it now contains nearly 20. The land has not increased in quantity, but the consumption of food has probably more than doubled. The importation from abroad has not increased to any important extent; by improved management, therefore, the same area of land has been caused to yield a double produce.

But the population will continue to increase; can we expect that the food raised from the land will continue to increase in the same ratio? This is an important question, to which we can give only an imperfect and somewhat unsatisfactory answer.

The superficial area of Great Britain comprises about 57 millions of acres, of which 34 millions are in cultivation, about 13 millions are incapable of culture, and the remaining 10 millions are waste lands susceptible of improvement. The present population, therefore, is supported by the produce of 34 millions of acres, or every 34 acres raises food for about 20 people. Suppose the 10 millions of acres which are susceptible of improvement to be brought into such a state of culture as to maintain an equal proportion—the most favourable supposition—they would raise food for an additional population of about 6 millions, or would keep Great Britain independent of any large and constant foreign supply till the number of its inhabitants amounted to 26 millions. But at the present rate of increase this will take place in about 20 years,* so that by 1860, unless some general improvement take place in the agriculture of the country, the demands of the population will have completely overtaken the productive powers of the land.

But though we cannot say how far the fertility of the soil may be increased, or how long it may be able to keep a-head of the growing numbers of the people, we have our own past experience, the example of other countries, and the indications of theory, all concurring to persuade us that the limit of its productive powers can neither be predicted nor foreseen.

If we glance at the history of British agriculture during the last half century—from the introduction of the green-crop system or the alternate husbandry from Flanders into Norfolk, up to the present time—we find the result of each successive improvement more remarkable than the former. The use of lime, a more general drainage of the soil, the invention of improved ploughs and other agricultural implements, as well as the introduction of better and more economical modes of using them, the application of bone manure, and more recently of thorough draining and subsoil ploughing, have all tended not only to the raising of crops at a less cost, but in far greater abundance, and on spots which our forefathers considered wholly unfit for the growth of corn.

The result of each new improvement, I have said, has seemed more astonishing than the former. For after a waste piece of land has been brought into an average state of productiveness, we are not prepared for any great improvement upon it by new labours; nor could we readily believe that, half a century after such land had been in culture, its produce or its value should at once be doubled, by a better draining, a deeper ploughing, or by sprinkling on its surface a small quantity of a saline substance imported from a foreign country.

Yet the example of the Chinese shows us that the productive powers of the soil are not to be easily estimated. Nothing repays the labours of the husbandman more fully than the willing soil—nothing is more grateful for his attention, or offers surer rewards to patient industry, or to renewed attempts at improvement.

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* For more precise data and calculations, see *Porter's Progress of the Nation.*

In China we see a people whom we call semi-barbarians, multiplying within their own limits till their numbers are almost incredible; practising from the most remote ages, and in the most skilful manner, various arts which the progress of modern science has but recently introduced into civilized Europe; cultivating their soil with the most assiduous labour, and stimulating its fertility by means which we have hitherto neglected, despised, or been wholly ignorant of—but which the discoveries of the present time are pointing out as best fitted to secure the amplest harvests—and have thus been enabled to compel their limited soil to yield a sufficient sustenance to its almost unlimited population.*

Experience and example, therefore, encourage us to look forward to still further improvements in the art of culture, and, independent of such as may be derived from purely mechanical principles, theoretical chemistry seems to point out the direction in which important advances of another kind may reasonably be anticipated. The Chinese are said to be not only familiar with the relative value and efficiency of the various manures, but also to understand how to prepare and apply without loss that which is best fitted to stimulate and support each kind of plant. How far this statement is exaggerated we are unable at present to determine, but it is in this direction that chemistry appears likely to promote the advance of European agriculture. The practical farmer already rejoices in having in one ton of bone dust the equivalent of 14 tons of farm-yard manure; some of the most skilful living chemists predict that methods will hereafter be discovered for compressing into a still less bulky form the substances required by plants, and that we shall live to see extensive manufactories established for the preparation of these condensed manures.*

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* An intelligent correspondent reminds me that the agricultural skill of the Chinese is questioned by recent writers on the customs of that country. This doubt is founded chiefly on the rudeness of their agricultural implements and the scarcity of cattle, whether horses or cows, among them. But in this densely peopled country the hoe they employ serves the purpose of every other implement (*Davis's China*, ii. 282), and, where the place of cattle is supplied by an equivalent number of men, there can be no comparative want of valuable manure. The population of China, however, is probably not so dense in all the provinces as it has hitherto been supposed. Many writers have estimated the entire population at 300 millions, while recent statists reduce it to 175 millions. Taking even the higher estimate, the population is not more dense than in England and Holland—the area of China proper being 1,200,000 square miles, or eight times that of France. It is considerably less dense, indeed, if we take into account the number of horses and cattle which in Europe are reared and fed on the produce of the land. We may hereafter expect more accurate information, however, especially regarding the interior of this interesting country.—*See Appendix A.*

Thus much may be said in regard to the future hopes and prospects of scientific agriculture.† But how few practical men are acquainted with what is already known of the principles of the important art by which they live! Trained up in ancient methods—attached generally to conservative principles in every shape—the practical agriculturists, as a body, have always been more opposed to change than any other large class of the community. They have been slow to believe in the superiority of any methods of culture which differed from their own, from those of their fathers, or of the district in which they live—and, even when the superiority could no longer be denied, they have been almost as slow to adopt them.

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* Should the opinions above expressed appear too sanguine to some, or be treated by any of my readers as *merely theoretical*, I would refer them to the words of Mr. Smith, of Deanston, the inventor of the subsoil plough, and the introducer of the greatest practical improvement in modern agriculture. After stating that *at least three-fourths of the whole arable land in the country is under very indifferent culture*, chiefly from the want of complete draining and deep working, and, adverting to the increased produce it may be made to yield, he says, "it is not at all improbable that Britain may become an exporting country in grain in the course of the next twenty years."—*Remarks on thorough draining and deep ploughing, by James Smith, Esq., of Deanston Works, p.* 22. Were the population to remain stationary, Mr. Smith may be right; at all events, this opinion shows that even practical men do not despair of attaining to a pitch of improvement in agriculture which theoretical writers dare not venture to predict.

But among all persons of enlarged information a similar opinion prevails. Thus the eloquent author of a recent work on the principles of population says, "the single alteration of substituting the kitchen-garden husbandry of Flanders in our plains, and the terraced culture of Tuscany in our hills, for the present system of agricultural management, would at once double the produce of the British Islands, and procure ample subsistence for twice the number of its present inhabitants."—*Alison's Principles of Population, I. p.* 216. These hopes are not to be rejected or suppressed; for, though they may never be fully realized, yet they are, as it were, the seeds of exertion, from which ample harvest of good may hereafter be reaped.

† Those who have access to the Journal of the Royal English Agricultural Society will find in the first number a paper by Mr. Pusey,

But the awakening spirit of the time is making itself felt in the remotest agricultural districts; old prejudices are dying out, and the cultivators of this most ancient, most important, and noblest of all the arts, are becoming generally anxious for information, and eager for improvement.[*]

Two circumstances have contributed to retard the approach of this better state of things.

In the first place, the agricultural interest in England has hitherto expended its main strength in attempting to secure or maintain important political advantages in the state. The encouragement of experimental agriculture has been in gene-

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“ On the present state of the science of Agriculture in England,” in which much valuable information is contained, and of a more practical kind than I have been able to introduce. This paper ought to be printed in a separate form, and circulated widely among those who are not members of the Royal English Agricultural Society.

[*] This opinion has been confirmed by the numerous communications I have received from all parts of the country since the publication of these Lectures was announced, and in which I am assured that the want of knowledge is generally felt, and a supply in a sufficiently elementary form desired, by all classes of agriculturists. I conclude, therefore, that Liebig means the following sentence to apply to his German countrymen: “ What can be expected from the present (generation of) farmers, which recoils with seeming distrust and aversion from all the means of assistance offered it by chemistry, and which does not understand the art of making a rational application of chemical discoveries.” I do not think chemists ought in fairness to blame the practical agriculturists for not understanding the art of applying chemical discoveries to the improvement of the culture of the land. They must first know what the discoveries are; and the error has hitherto been, that no steps have been taken to diffuse this preliminary knowledge.

ral neglected, while the diffusion of practical knowledge has been either wholly overlooked or considered subordinate to other objects. No national efforts have been made for the general improvement of the methods of culture. While for the other important classes of the community special schools have been established, in which the elements of all the branches of knowledge most necessary for each class have been more or less completely taught, and a more enlightened, because better instructed, race of men gradually trained up, no such schools have been instituted for the benefit of the agriculturist. In our Universities, in which the holders of land, those most interested in its improvement, are nearly all educated, a lesson upon agriculture, the right arm of the State, has hitherto scarcely ever been given.* With the practice of the art, the theory has also been neglected. Scientific men have had no

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* However satisfied young men may be to avoid the labour of additional study while at College, how many in after-life regret that their early attention had not been directed to some of those branches of knowledge which are applicable to common life. Thus the late Lord Dudley, in his letters to the Bishop of Llandaff, invariably laments, "as mistakes in his early life, his unacquaintance with the rudiments of agriculture—his ignorance of botany and geology."—(See also a note to the review of these Letters in the Quarterly Review for December, 1840.)

For this state of things we shall soon have at least a partial remedy. It is a remarkable fact that nearly all the new educational institutions of the higher class, on the Continent of Europe, of which so many have been founded within the present century, and all those which have been established in America, I believe, without exception, have incorporated into their course of general study one or more of the newer sciences. Can we have a more consentaneous and universal testimony to their value and importance than this? The University of London has been induced, by the same public demand for this species of instruction, to include Chemistry and Botany in its course of arts; and circumstances only have caused Geology to be omitted for a time. Its numerous affiliated institutions have followed its steps; and hence the Catholic College of St. Cuthbert, at Ushaw, has in this respect anticipated its Protestant neighbor at Durham.

But should the agricultural interest rest satisfied with this introduction of one or two branches, suppose it generally done, into the University course of study? Many are of opinion that it ought not, and that the general interests of practical agriculture would be manifestly promoted, among other means, by the establishment of agricultural colleges, in which all the branches necessary to be known by enlightened agriculturists of every class should be specially and distinctly taught. Whether such Colleges might inducement to devote their time and talents to a subject which held out no promise of reward, either in the shape of actual emolument or of honorary distinction. And thus has arisen the second of those circumstances, by which I consider the approach of a better state of things to have been retarded—namely, the want of an *Agricultural Literature.*

With the exception of a small number of periodical publications, none of these even too well supported, by which attempts have been zealously made to diffuse important information among the practical farmers—it cannot be denied that the press has not been encouraged to do its utmost on behalf of agricultural knowledge in general—while the single work of Sir Humphry Davy is nearly all that chemical science has, in this country, been induced to contribute to the advancement of agricultural theory during the last forty years.*

Many of you have probably read this work of Sir H. Davy, and are prepared to acknowledge its value. Yet how many things does he pass over entirely, how many things leave unexplained. Since his time, not only have numerous practical observations and discoveries been made, but the entire science of animal and vegetable chemistry has been regenerated. We are not, therefore, to expect in his work a view of the present state, either of our theoretical knowledge, or of our practical agriculture. It belongs rather to the history of the progress of knowledge than to the condition of existing information. Hence the merits of the agricultural chemistry of Davy are not to be tried by its ac-

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be beneficially annexed to the existing Universities, is a question deserving of serious consideration.

* The latest edition of Lord Dundonald's "Treatise on the intimate connection between Chemistry and Agriculture," which I have seen, is dated London, 1803.

I should be doing injustice to a good chemist and a zealous agriculturist, were I not to direct the attention of my readers to a series of excellent articles on chemical agriculture by Dr. Madden, inserted in the numbers of the Quarterly Journal of Agriculture for the last two years.

Since the above went to press, Three Lectures on Agriculture have appeared from the pen of Dr. Daubeny, of Oxford, whose name will secure them an extended circulation.

cordance with actual knowledge, but with what was known in 1812, when its distinguished author read his course of lectures for the last time before the Board of Agriculture.

We may with certainty predict, however, that neither the practice nor the theory of agriculture will be permitted to experience in future that want of general encouragement under which during the last half century they have in England been permitted to languish. The public mind has been awakened, and the establishment of Agricultural Associations, provincial and local, are manifestations of the interest now felt upon the subject in all parts of the country. It requires only the general exhibition of such an interest, and the adoption of some general means of encouragement, to stimulate both practical ingenuity and scientific zeal to expend themselves on this most valuable branch of national industry.

Science is never unwilling to lend her hand to the practical arts; on the contrary, she is ever forward to proffer her assistance, and it is not till her advances have been rejected or frequently repulsed, that she refrains from aiding in their advancement.

Need I advert, in proof of this, to the unwearied labours of the vegetable physiologists—or to the many valuable observations and experiments recorded in the memoirs of scientific chemists. In these memoirs, or in professedly scientific works, such observations have not unfrequently been permitted to rest;—the public mind being unprepared either to appreciate their value or to encourage the exertions of those who were willing to give them a practical and popular form.

And how numerous are the branches of science connected with this art? Need I speak of botany, which is, as it were, the foundation on which the first elements of agriculture rest; or of vegetable physiology, to the indications of which it has hitherto almost exclusively looked for improvement and increased success; or of zoology, which alone can throw light on the nature of the numerous insects that prey upon your crops, and so often ruin your hopes,—and which can alone be reasonably expected to arm you against their ravages, and instruct you to extirpate them? Meteorology among her other labours tabulates the highest, the mean, and the lowest, temperatures, as well as the quantity of rain which falls during each day and each month of the year. Do you doubt the importance of such knowledge to the proper cultivation of the land? Consider the destructive effects of a late frost in spring, or of a continued heat in summer, and your doubts will be shaken. A wet season in our own climate brings with it many evils to the practical agriculturist; but what effect must the rain have on the soil, in countries where nearly as much falls in a month, as in England during the course of a whole year;*—where every thing soluble is speedily washed from the land, and nothing seems to be left but a mixture of sand and gravel? It may indeed be said with truth, that no department of natural science is incapable of yielding instruction—that scarcely any knowledge is superfluous—to the tiller of the soil.

It is thus that all branches of human knowledge are bound together, and all the arts of life, and all the cultivators of them, mutually dependent. And it is by lending each a helping hand to the others, that the success of all is to be secured and accelerated; while with the general progress of the whole the advance of each individual is made sure.

The recent contributions and suggestions of geology are the best proof of the readiness of the sciences of observation to give their aid to the promotion, especially of agricultural knowledge. The geologist can best explain the immediate origin of your several soils, the cause of the diversities which even in the same farm, it may be in the same field, they not unfrequently exhibit;† the nature and differences among your subsoils, and the advantages you may expect from breaking them up or bringing them to the surface.

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* At Canton, in the month of May, the fall of rain is often as much as 20 inches.

† I cannot refer to a plainer, more simple, or more beautiful illustration of this fact than that which is presented in a short paper by Sir John Johnstone, Bart., inserted in the Journal of the English Agricultural Society, I. p. 271, entitled "On the Application of Geology to Agriculture." See also an able paper by the Rev. Mr. Thorpe, of which a valuable report is contained in the Doncaster Chronicle of December 5th, and which will be published in the proceedings of the Geological and Polytechnic Society of the West Riding of Yorkshire.

Geology is essentially a popular science, and the talents of its eminent English cultivators are admirably fitted to make it still more so. Hence, a certain amount of knowledge of this science has been of late years very generally diffused, and its relations to agriculture are becoming every day better understood. The Highland Society of Scotland, among its many other useful exertions, has done very much to connect agriculture and geology with the sphere of its own labours, while the Journal of the Royal Agricultural Society of England manifests a similar desire on the part of that numerous and talented body, to illustrate the connection of agriculture with geology and chemistry, in the southern division of the island. That Dr. Buckland, Mr. Murchison, and Mr. De la Beche, have each engaged to make a gratuitous survey of the subsoils in several extensive agricultural districts, at the request of the Council of this Society,* shows that, where their services are estimated, our most eminent scientific men will not hesitate to devote them to the development of the most important branches of national industry.

The time, therefore, is peculiarly favourable for the increase and diffusion of agricultural knowledge. The growth of our population requires it—practical men are anxious to receive instruction—scientific men are eager to impart what they know, and to make new researches for the purpose of clearing up what is unknown—are we not justified, therefore, in anticipating hereafter a constant and general diffusion of light, a steady progress of agricultural improvement?

Having thus glanced at the state and prospects of scientific agriculture in general, and especially of the art of culture in England, permit me to advert to a few of those questions of daily occurrence among you, to which chemistry alone can give a satisfactory answer. I shall not in this place allude to the subject of manures—which form alone an entire chapter of most recondite chemistry, and which I shall take up in its proper place, but I shall select a few isolated topics, the bearing of chemical knowledge upon which is sufficiently striking

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* Journal of the Royal Agricultural Society, Report of their Council, I. p. 188.

To form a just idea of the value and importance of such surveys, it is only necessary to read chap. xv., pp. 463 to 480, of Mr. De la Beche's "Geological Report on Cornwall and Devon," or Professor Hitchcock's "Report on a re-examination of the Economic Geology of Massachusetts."

Some soils are naturally barren, but how few of our agriculturists are able, in regard to such soils generally, to say why; how few who possess the knowledge requisite for discovering the cause! Of these barren lands some may be improved so as amply to repay the outlay; some from their locality or from other causes, are in the present state of our knowledge irreclaimable. How important to be able to distinguish between these two cases!

Some apparently good soils are yet barren in a high degree. In endeavouring to improve such soils, practical men have no general rule—they can have none. They work in the dark—like a man who makes experiments in a laboratory, without a teacher or without a book, till, after many blunders and much expense, he discovers some fact, to himself new, but to others long known, and forming only one of many analogous facts, flowing from a common, and probably well-understood, principle.

"The application of chemical tests to such a soil," says Sir Humphry Davy, "is obvious. It must contain some noxious principle,* which may be easily discovered and probably easily destroyed. Are any of the salts of iron present, they may be decomposed by lime. Is there an excess of siliceous sand, the system of improvement must depend on the application of clay and calcareous matters. Is there a defect of calcareous matter, the remedy is obvious. Is an excess of vegetable matter indicated, it may be removed by liming, paring, and burning. Is there a deficiency of vegetable matter, it is to be supplied by manure."†

What was true in regard to the applications of chemistry in the time of Sir Humphry Davy, is more true in a high degree of the chemistry of our time. Not only is the nature of soils better understood, but we know in many cases what a soil *must* contain before it will produce a given crop. Why do pine forests settle themselves on the naked and apparently barren rocks of Scotland and of Northern Europe, content if their young roots can find but a crevice in the mountain to shelter them? Why does the beech luxuriate in the alluvial soils of Southern Sweden, of Zealand, and Continental Denmark? Why does the birch spring up from the ashes of the pine forest—why the rapid rush of delicate grass from the burned prairies of India and of Northern America? Whence comes the thick and tender sward of the mountain limestone districts—whence the gigantic wheat stock of a virgin soil? Why do the same forest trees propagate themselves for ages on the same spots without impoverishing the soil—why do the natural grasses, the longer they are undisturbed, render the land only the more fertile?

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* Or be deficient in some necessary element.—J.

† Agricultural Chemistry, Lecture I.

These, one would think, are scarcely chemical questions; and yet to all of them, and to a thousand such, chemistry alone can and will give a satisfactory answer.

The rotation of crops is a practical rule, the benefit of which has been proved by experience; it becomes a true philosophical principle of action, when we discover the causes from which this benefit springs. Botany has thrown considerable light, and of an interesting and important kind, upon this practice, but chemistry has fully cleared it up and established the principle.

Sir Humphry Davy speaks of the use of lime. Can you explain the mysterious, and apparently fickle and diversified, agency of this substance in reference to vegetation? Are the advantages so frequently attended upon its use to be ascribed to the chemical character of the soil to which it is applied, to the kind and quantity of the vegetable matter it contains, or to the geological nature of the rocks on which it rests? Are they dependent upon the drainage and exposure of the land—on the kind of crop to be raised—on the general climate of the district—on the maxima and minima of temperature—or on the quantity of rain which falls?

So with gypsum. Why are its effects lauded in one district, doubted in another, and decried in a third! Are no rules or principles to be discovered, by which these diversified effects are to be explained, and the true purpose and fit use of these and other mineral substances clearly pointed out? Such principles are yet to be sought for; but if sought by the way of well devised and accurately conducted experiment, they are *sure* to be discovered.

The land is exhausted by frequent cropping. What language more familar, what statement more true than this? Yet how few understand what exhaustion implies; how few can explain either how it takes place, by what means it can be remedied, or how, if left to herself, nature at length does apply a remedy!

Have you any doubt in regard to the prevailing ignorance on the subject? To be satisfied, you have only to look with an experienced eye on the agricultural practice of the county of Durham. Are there not thousands of acres in the centre of this county which exhibit a degree of unproductiveness not natural to the soil;—which have been over-cropped, and worn out, and impoverished? A soil comparatively fertile by nature has been rendered unfertile by art. That which was naturally good has been rendered as unproductive and unprofitable as that which was naturally bad. Has this state of things arisen from ignorance, from design, or from necessity? By whichever of these it has been immediately caused, it is clear that the requisite degree of knowledge on the part of the owners of the soil would have retarded if not wholly prevented it.

The same knowledge will enable them to reclaim these lands again, and gradually restore them to a more fertile condition; for the changes which the soil undergoes in such circumstances are all chemical changes,—either in the relative quantities of the substances it contains, or in the state of combination in which they exist.

The art of culture indeed is almost entirely a chemical art, since nearly all its processes are to be explained only on chemical principles. If you add lime or gypsum to your land, you introduce new chemical agents. If you irrigate your meadows, you must demand a reason from the chemist for the abundant growth of grass which follows. Do you find animal manure powerful in its action, is the effect of some permanent, while that of others is speedily exhausted ?—Does a mixture of animal and vegetable manure prepare the land best for certain kinds of grain ?—Do you employ common salt, or gypsum, or saltpetre, or nitrate of soda, with advantage ?—In all these cases you observe chemical results which you would be able to control and modify did you possess the requisite chemical knowledge.

It is not wonderful that even theoretical agriculturists should be far behind in the knowledge of those principles on which their most important operations depend. The greatest light has been thrown upon the art of culture by the researches of organic chemistry, a branch which may be said to have started, if not into existence, at least into a new life, within the last ten years. Every day too is adding to the number and value of its discoveries, and the agriculturist may well be pardoned for not keeping pace with the advances of a department of science, which even the professed and devoted chemist can scarcely overtake.

I might advert also to the mechanical operations of ploughing, whether common or subsoil, of following draining, weeding, and many others, as being only so many methods by which chemical action is induced or facilitated ;—to the growth of plants, and even to such observed differences as that of the relative quantity of leaves and tubers in the potato, and of grain and straw in our corn-fields, as interesting cases on which scientific chemistry throws a flood of light. I might show how the feeding of your cattle and the raising and management of dairy produce are not beyond the province of chemistry, but that the only approach to scientific principle yet made, even in these branches of husbandry, is derived from the results of chemical research.

But I do not dwell on any of these points : they will all hereafter come under our review in their appropriate order, and will afford me an opportunity of laying before you many important facts, as well as, I hope, valuable practical deductions and observations.

While, however, I feel justified in saying thus much of the light which existing chemical knowledge throws on the natural processes of vegetation, and on the artificial methods of practical agriculture, I would not lead you to suppose that our knowledge is by any means complete, that there are not many points over which much darkness still rests—that some of the theoretical views now entertained are not crude, adopted too hastily, and generalized too rapidly. But a similar confession may be made in reference to all the modern sciences of observation without diminishing their importance or detracting from the value of the facts they embody. Human science is progressive in all its branches, and to refuse to follow the indications of existing knowledge because it is to some extent uncertain, would be as foolish as to refuse to avail ourselves of the morning's light, because it is not equal to that of the midday sun.

I advance, therefore, to the special object of these lectures, and I shall first present you with a rapid outline of the method which I intend to follow. It is indispensable that this method should be simple, and that every consecutive portion should be so fitted to clear the way for, and throw light upon, what is to follow, that we may be able to advance from the first rudiments to the most difficult and abstruse parts of our subject, without any chance of the illustrations being even difficult to comprehend. This end I do not hope perfectly to attain, but it will be my constant aim, and, with due attention on your part, I do not fear that we shall fail in arriving at a perfect understanding of the various points to which I shall have occasion to direct your attention.

I propose, therefore, to bring before you—

I. The constitution of vegetable substances with the properties of the elementary and compound bodies which either enter into the substances of plants or contribute to their growth and nourishment.

II. The general structure and functions of the several parts of plants—their mode of growth—and the manner in which their food is absorbed, changed, and converted into parts of their substance.

III. The origin, nature, and principal differences of soils—with the circumstances on which their relative fertility depends, or under which it is modified.

IV. The nature and differences of manures, and their mode of action, whether directly in supplying food to the plant, or indirectly in hastening and increasing their growth.

V. The nature and diversities of the food raised as the result of culture—especially in reference to their several equivalents or powers of supporting animal life.

Under this head the feeding of cattle and the variations in the quantity and quality of dairy produce, will form subjects of consideration.

These different branches, I believe, comprehend the whole subject of chemical agriculture; in regard to all of them we shall derive either from chemistry or geology much important information.

§ 1. *Different kinds and states of Matter.*

All the forms of matter which present themselves to our view, whether in the solid crust of the globe on which we live, in the air which forms the atmosphere by which we are surrounded, or in the bodies of animals and plants—all are capable of being divided into the two great groups of organic and inorganic matter. The solid rocks and soils, the atmosphere, the waters of the seas and oceans, every thing which neither is nor has been the seat of life, may generally be included under the head of inorganic matter. The bodies of all living animals and plants, and their dead carcasses, consist of organic or organized matter. These generally exhibit a kind of structure readily visible by the eye, as in the pores of wood, and in the fibres of hemp, or of the lean of beef,* and are thus readily distinguished from inorganic matter, in which no such structure is observable.

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* The pores of wood and fibres and minute vessels in animals being the *organs* or instruments of life, the substances themselves are called organized or organic.

But in many substances of organic origin also, no structure is observable. Thus, sugar, starch, and gum, are formed in plants in great abundance, and yet do not present any pores or fibres; they have never been endowed with organs, yet being produced by the *agency* of living organs, they are included under the general name of organic matter. So when animals and plants die, their bodies undergo decay, but the matter of which they are composed is considered as of organic origin, not only as long as any traces of structure are observable, but even after all such traces have disappeared. Thus coal is a substance of organic origin, though almost all traces of the vegetable matter from which it has been derived, have been long ago obliterated.

Again, heat chars and destroys wood, starch, and gum, forming black substances totally unlike the original matter acted upon. By distillation, wood yields tar and vinegar; and by fermentation, sugar is converted first into alcohol, and then into vinegar. All substances derived from vegetable or animal products by these and similar processes are included under the general designation of organic bodies.

Now if we take a portion of almost any of those numerous forms of matter which we meet with either in the inorganic or in the organic kingdoms, we find, that on subjecting it to certain chemical processes, it is capable of being resolved or separated into more than one substance. Thus coal when put into a gas retort is resolved into tar, coal gas, and certain other substances. Wood, when treated in the same way, yields pyroligneous acid, tar, and water, and leaves behind a residue of charcoal. If again we subject charcoal to the action of heat (not in the open air), or to any other process we can devise, we can never separate any thing further from it. After all our operations we obtain only charcoal.

So a piece of common lead ore, when heated in a similar manner, will, if pure, give off sulphur only, and leave the lead behind, from which nothing but lead can afterwards be extracted.

Thus it is evident that wood and the ore of lead differ from charcoal and metallic lead in this respect, that the former consist of more than one kind of matter, the latter of one kind of matter only. Hence charcoal and lead are called *simple* or *elementary* bodies, while wood and all other substances which are capable of being resolved into two or more different kinds of matter, are called *compound* bodies.

The diversified forms of matter which present themselves to our notice in the mineral crust of the globe, and in the organs and vessels of plants and animals, are absolutely without number. We can no more reckon them than we can the stars of heaven. Yet it is one of those results of modern chemistry which to the mind not yet familiarized with chemical discoveries appears most wonderful,—that these numberless forms of matter are capable of being resolved into, and therefore are composed or made up of, only 55* of those simple or elementary substances, the nature of which has been above explained. Occasionally these elementary substances occur in a separate state, as in native† gold and silver, but they are generally found associated together, forming substances from which several of the 55 simple bodies may be extracted.

All the material substances in nature consist of one or more of these 55 elementary bodies. This is sufficiently surprising, yet it is, if possible, still more remarkable that nearly the entire mass of every vegetable substance may be resolved into one or more of *four* only of these simple substances.

When a portion of animal or vegetable matter is burned, it either entirely disappears or leaves behind it only a small quantity of ash. Animal and vegetable oils and fats, gum, sugar, and starch, when burned, disappear entirely; a piece of wood or of lean meat leaves a small quantity of earthy (inorganic) matter behind.

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* The names of these elementary bodies are as follows:—Oxygen, hydrogen, nitrogen, sulphur, selenium, phosphorus, chlorine, bromine, iodine, fluorine, carbon, boron, silicon, potassium, sodium, lithium, barium, strontium, calcium, magnesium, aluminium, glucinium, yttrium, zirconium, thorium, cerium, lanthanium, manganese, iron, cobalt, nickel, zinc, cadmium, lead, tin, bismuth, copper, uranium, mercury, (quicksilver), silver, palladium, iridium, platinum, gold, osmium, titanium, tantalum, (columbium), tungsten, molybdenum, vanadium, chromium, antimony, tellurium, arsenic.

† So called when found in the malleable state.

In or upon the soil charcoal for a time will act in the same manner, will absorb from the air moisture and gaseous substances, and from the rain and from flowing waters organized matters of various kinds, any of which it will be in a condition to yield to the plants which grow around it, when they are such as are likely to contribute to their growth.

3°. They have the property also of absorbing disagreeable odours in a very remarkable manner. Hence animal food keeps longer sweet when placed in contact with charcoal—hence also vegetable substances containing much water, such as potatoes, are more completely preserved by the aid of a quantity of charcoal—and hence the refuse charcoal of the sugar refiners is found to deprive night-soil of its disagreeable odour, and to convert it into a dry and portable manure. 4°. They exhibit also the still more singular property of extracting from water a portion of the saline substances they may happen to hold in solution, and thus allowing it to escape in a less impure form. The decayed (half carbonized) roots of grass, which have been long subjected to irrigation, may act in one or all of these ways on the more or less impure water by which they are irrigated—and thus gradually arrest and collect the materials which are fitted to promote the growth of the coming crop.

§ 3. *Oxygen—its properties and relations to vegetable life.*

Oxygen is a substance with which we are acquainted only in the gaseous or aeriform state.* By the unaided senses it cannot be distinguished from common air, being void of colour, taste and smell. But if a lighted taper be plunged into it, the flame is wonderfully increased both in size and brilliancy, and the taper burns away with great rapidity.

The effect of this gas upon animal life is of a similar kind. When a living animal is introduced into a large vessel filled with oxygen, the rapidity of the circulation is increased, all the vital functions are stimulated and excited, a state of fever comes on, and after a time the animal dies.

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* In this state it is readily obtained by heating in a glass retort the red oxide of mercury of the shops, or a white salt known by the name of chlorate of potash.

By these two characters, oxygen is distinguished from every other elementary body. It exists in the atmosphere to the amount of 21 per cent. of its bulk, and in this state of air is necessary to the existence of animals and of plants, and to the support of combustion on the face of the globe. It exists also largely in water, every nine pounds of this liquid containing eight pounds of oxygen.

But the quantity of this substance which is stored up in the solid rocks is still more remarkable. Nearly one-half of the weight of the solid rocks which compose the crust of our globe, of every solid substance we see around us—of the houses in which we live, and of the stones on which we tread—of the soils which you daily cultivate, and much more than one-half by weight of the bodies of all living animals and plants, consist of this elementary body oxygen, known to us, as I have already said, only in the state of a gas. It may not appear surprising that any one elementary substance should have been formed by the Creator in such abundance as to constitute nearly one-half by weight of the entire crust of our globe, but it must strike you as remarkable, that this should also be the element on the presence of which all animal life depends—and as nothing less than wonderful, that a substance which we know only in the state of thin air, should, by some wonderful mechanism, be bound up and imprisoned in such vast stores in the solid mountains of the globe, be destined to pervade and refresh all nature in the form of water, and to beautify and adorn the earth in the solid parts of animals and plants. But all nature is full of similar wonders, and every step you advance in the study of the principles of the art by which you live, you will not fail to mark the united skill and bounty of the same great Contriver.

Oxygen gas is heavier than common air in the proportion of about 11 to 10;* it is also capable of being absorbed by water to a certain extent. One hundred measures of water dissolve 6½[*] of this gas. Rain, spring, and river waters, always contain a portion of oxygen which they have derived from the atmosphere, and this oxygen as they trickle through the soil, ministers to the growth and nourishment of plants in various ways. Some of these will be explained in a subsequent lecture.

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* Its specific gravity by experiment is 1·1026, air being 1.

In an atmosphere of pure oxygen gas, plants refuse to vegetate and speedily perish.

§ 4. *Hydrogen—its properties and relations to vegetable life.*

Hydrogen is also known to us only in the state of gas, and when perfectly pure agrees with oxygen and common air in being without colour, taste, or smell. It is not known to occur in nature in a free or simple state, nor does it exist so abundantly as either carbon or oxygen. It forms a small per centage of the weight of all animal and vegetable substances, and constitutes one-ninth of the weight of water, but with the exception of coal, it does not enter as a constituent into any of the large mineral masses that exist in the crust of the globe.

When a lighted taper is plunged into this gas it is immediately extinguished, but if in contact with the air the gas itself takes fire and burns with a pale yellow flame. If previously mixed with air or with oxygen gas, it kindles and burns with a loud explosion. During this combustion water is formed.[†]

It does not support life, animals cease to breathe when introduced into it, and plants gradually wither and die. It is the lightest of all known substances, being about 14½ times lighter than common air,[‡] so that if the stopper be removed from a bottle in which it is contained it almost immediately escapes. It is the element which is employed to give buoyancy to balloons; and by this great levity and its relations to flame it is readily distinguished from all other known substances.

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[*] De Saussure. According to Dr. Henry, 100 volumes of water absorb only 3½ of oxygen.

[†] See the Second Lecture.

[‡] Its specific gravity, by experiment, is 0·0687, air being 1.

Water absorbs it only in very small quantities, 100 gallons taking up no more than about 1¼ gallons of hydrogen gas. But, as already observed, this gas does not exist in nature in a free state—is not necessary, therefore, to the growth of plants or animals in this state—and hence its insolubility in water is in unison with the general adaptation of every property of every body, to the health and growth of the highest orders of living beings.

Hydrogen gas is readily obtained from water by putting into it a few pieces of metallic iron or zinc, and adding a little sulphuric acid (oil of vitriol). Bubbles of the gas are liberated from the surface of the metal, ascend through the water, and may be collected on the surface.

§ 5. *Nitrogen—its properties and relations to vegetable life.*

Nitrogen is also known to us only in the form of gas. It exists in the atmosphere to the amount of 79 per cent. of its bulk. It is without color, taste, or smell. Animals and plants die in this gas, and a taper is instantly extinguished when introduced into it; the gas itself undergoing no change. It is lighter than atmospheric air, in the proportion of 97¼ to 100.* It is an essential constituent of the air we breathe, serving to temper the ardour with which combustion would proceed and animals live in undiluted oxygen gas. It forms a part of very many animal and of some vegetable substances, but it is not known to enter into the composition of any of the great mineral masses of which the earth's crust is made up. In coal alone, which is of vegetable origin, it has been detected to the amount of one or two per cent. It is therefore much less abundant in nature than any of the other so called organic elements—and it exhibits much less decided properties than any of them; yet we shall hereafter see that it performs certain most important functions in reference both to the growth of plants and to the nourishment of animals.

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* Its density is 0·976, air being 1.

One hundred volumes of water dissolve about 1½ volumes of this gas.* Spring and rain waters absorb it as they do oxygen, from the atmospheric air, and bear it in solution to the roots, by which it is not unlikely that it may be conveyed directly into the circulation of plants.

Such are the several elementary bodies of which the organic or destructible part of vegetable substances is formed. With one exception they are known to us only in the form of gases; and yet out of these gases much of the solid parts of animals and of plants are made up. When alone, at the ordinary temperature of the atmosphere they form invisible kinds of air; when united, they constitute those various forms of vegetable matter which it is the aim and end of the art of culture to raise with rapidity, with certainty, and in abundance. How difficult to understand the intricate processes by which nature works up these raw materials into her many beautiful productions—yet how interesting it must be to know her ways, how useful even partially to find them out!

Permit me, in conclusion, to submit to you one reflection. We have seen that oxygen, hydrogen, and nitrogen, are all gaseous substances, which when pure are destitute of colour, taste, and smell. They cannot be distinguished by the aid of our senses. Man in a state of nature—uneducated man—cannot discern that they are different. Yet so simple an instrument as a lighted taper at once shows them to be totally unlike each other. This simple instrument, therefore, serves us instead of a new sense, and makes us acquainted with properties the existence of which, without such aid, we should not even have suspected. Has the Deity then been unkind to man, or stinted in his benevolence in withholding the gift of such a sense. On the contrary, he has given us an understanding which when cultivated is better than twenty new senses. The chemist in his laboratory is better armed for the investigation of nature, than if his organs of sense had been many times multiplied. He has many instruments at his command, each of which, like the taper, tells him of properties which neither his senses nor any other of his instruments can discover; and the further his researches are carried, the more willing does nature seem to reveal her secrets to him, and the more rapidly do his chemical senses increase. Do you think that the rewards of study and patient experimental research are confined to the laboratory of the chemist, and that the Deity will prove less kind to you, whose daily toil is in the great laboratory of nature? As yet you see but faintly the reason of many of your commonest operations, and over the results you have comparatively little control—but the light is ready to spring up, the means are within your reach—you have only to employ your minds as diligently as you labor with your hands, and ultimate success is sure.

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* Henry De Saussure says, that pure water absorbs 4 per cent. of its bulk of this gas.

LECTURE II.

Characteristic properties of organic substances—Relative proportions of organic elements—Variable proportions of inorganic elements in plants—Form in which the organic elements are taken up by plants—The atmosphere, its constitution and relations to vegetable life—Nature and laws of chemical combination—Water and its relations to vegetable life.

§ 1. *Characteristic properties of organic substances.*

Of the four elementary substances described in the former lecture, the organic part of all animal and vegetable substances consists. What is understood by the term organic has also been explained.

But organic substances possess certain characters by which they are distinguished from the inorganic or dead matter of the globe, and on which their connection with the principle of life, and with the art of culture, entirely depends. These characteristic properties are chiefly the following.

1°. They are all easily decomposed or destroyed by a moderately high temperature. If wood or straw be heated in the air, as over the flame of a candle, it becomes charred, burns, and is in a great measure dissipated. So sugar and starch darken in colour when heated, blacken, and take fire. The same is true of all vegetable substances. But limestone, clay, and other earthy or stony matters, undergo no apparent change in such circumstances—they are not decomposed.

2°. When exposed to the air, especially if it be warm and moist, vegetable and animal substances putrify and decay.* They decompose of their own accord, and after a time almost entirely disappear. Such is not the case with inorganic matters. If the rocks and stones crumble, their particles may be washed away by the rains to a lower level; but they never putrify or wholly disappear.

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* For an explanation of the exact nature and end of this putrefaction, see the subsequent Lecture, "*On the decay of animal and vegetable substances.*"

3°. They consist almost entirely of two or more of the four organic elements only. The mineral substances we meet with on the earth's surface, and collect for our cabinets, often contain portions of many elementary bodies; but, with few exceptions, the organic part of all plants, that which lives and grows, contains only the four simple substances described in my former lecture.

4°. They are distinguished also by this important character, that they cannot be formed by human art. Many of the inorganic compounds which occur in the mineral crust of the globe can be produced by the chemist in his laboratory, and were any corresponding benefit likely to be derived from the expenditure of time and labour, there is reason to believe that, with a few exceptions, nature might be imitated in the formation of any of her mineral productions. But in regard to organic substances, whether animal or vegetable, the chemist is perfectly at fault. He can form neither woody fibre, nor sugar, nor starch, nor muscular fibre, nor any of those substances which constitute the chief bulk of animals and plants, and which serve for the food of animated beings. This is an important and striking, and is, I believe, likely to remain a permanent distinction, between most substances of organic and of inorganic origin.

Looking back at the vast strides which organic chemistry has made within the last twenty years, and is still continuing to make, and trusting to the continued progress of human discovery, some sanguine chemists venture to anticipate the time when the art of man shall not only acquire a dominion over that principle of life, by the agency of which plants now grow and alone produce food for man and beast, but shall be able also, in many cases, to imitate or dispense with the operations of that principle; and to predict that the time will come when man shall manufacture by art those necessaries and luxuries for which he is now wholly dependent on the vegetable kingdom.

And, having conquered the winds and the waves by the agency of steam, is man really destined to gain a victory over the uncertain seasons too? Shall he come at last to tread the soil beneath his feet as a really useless thing—to disregard the genial shower, to despise the influence of the balmy dew—to be indifferent alike to rain and drought, to cloud and to sunshine—to laugh at the thousand cares of the husbandman—to pity the useless toil and the sleepless anxieties of the ancient tillers of the soil? Is the order of nature, through all past time, to be reversed—are the entire constitution of society, and the habits and pursuits of the whole human race, to be completely altered by the progress of scientific knowledge?

By placing before man so many incitements to the pursuit of knowledge, the will of the Deity is, that out of this increase of wisdom he should extract the means of increased happiness and enjoyment also. But set man free from the necessity of tilling the earth by the sweat of his brow, and you take from him at the same time the calm and tranquil pleasures of a country life—the innocent enjoyments of the returning seasons—the cheerful health and happiness that wait upon labour in the free air and beneath the bright sun of heaven. And for what?—only to imprison him in manufactories, to condemn him to the fretful and feverish life of crowded cities.

To such ends, I trust, science is not destined to lead; and he is not only unreasonably, but thoughtlessly sanguine, who would hope to derive from organic chemistry such power over dead matter as to be able to fashion it into food for living animals. With such consequences before us it seems almost sinful to wish for it.

Yet, that this branch of science will lead to great ameliorations in the art of culture, there is every reason to believe. It will explain old methods—it will clear up anomalies, reconcile contradictory results by explaining the principles from which they flow—and will suggest new methods by which better, speedier, or more certain harvests may be reaped.

§ 2. *Relative proportions of organic elements.*

Though the substance of plants consists chiefly of the four organic elements, yet these bodies enter into the constitution of vegetables in very different proportions. This fact has already been adverted to in a general manner; it will appear more distinctly by the following statement of the exact quantities of each element contained in 1000 parts by weight of some of the more important kinds of vegetable substances you are in the habit of cultivating :—

	Hay from young Clover 3 months old	Oats.	Clover Seed.	After-math Hay.	Peas.	Wheat.	Hay.	Potatoes.
Carbon . .	507	507	494	471	465	455	458	441
Hydrogen .	66	64	58	56	61	57	50	58
Oxygen . .	389	367	350	349	401	431	387	439
Nitrogen .	38	22	70	24	42	34	15	12
Ash . . .	not stated	40	28	100	31	23	90	50
	1000*	1000†	1000*	1000†	1000‡	1000*	1000†	1000†

The numbers in the above table represent the constitution of the plants and seeds taken in the state in which they are given to cattle or are laid up for preservation, and then dried at 230° Fahrenheit. By this drying they lost severally as follows :

1000 parts	of Potatoes. . .	lost . .	722	parts of water.
ditto	of Wheat. . .	— . .	166	ditto.
ditto	of Hay. . . .	— . .	158	ditto.
ditto	of Aftermath Hay	—	136 to 140	ditto.
ditto	of Oats. . . .	— . .	151	ditto.
ditto	of Clover Seed .	— . .	112	ditto.
ditto	of Peas. . . .	— . .	86	ditto.

In crops as they are reaped, therefore, and even as they are given for food, much water is present. When artificially dried, the carbon approaches to one-half of their weight—the oxygen to more than one-third*—the hydrogen to little more than 5 per cent. and the nitrogen rarely to more than 2½ per cent. These proportions are variable, but they represent very nearly the relative weights in which these elements enter into the constitution of those forms of vegetable matter which are raised in the greatest quantity for the support of animal life.

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* Boussingault Annales de Chim. et de Phys, (1838) LXVII. p. 20 to 38.
† Ditto Ibid (1839) LXXI. p. 113 to 136.
‡ Ditto Ibid (1838) LXIX. p. 356.

But, besides the organic part, vegetable substances contain an inorganic portion, which remains behind in the form of ash when the plant is consumed by fire, or of dust when it decomposes and disappears in consequence of natural decay.

In the dried hay, oats, &c., of which the composition is represented in the above table, we see that the quantity of ash is very variable, in oats being as small as 4 per cent., while of hay every hundred pounds left 10 of ash. A similar difference is observed generally to prevail throughout the vegetable kingdom. Each variety of plant, when burned, leaves a weight of ash, more or less peculiar to itself. Herbaceous plants generally leave more than the wood of trees—and different parts of the same plant yield unlike quantities of inorganic matter.† These facts are of great importance in the theory and in the enlightened practice of agriculture. They will hereafter come under special and detailed consideration, when we shall have examined the nature of the soils in which plants grow, and shall be prepared to consider the chemical nature, the source, and the functions, of the inorganic compounds which exist in living animal and vegetable substances.

§ 3. *Of the form or state of combination in which the organic elements enter into and minister to the growth of plants.*

From the details already presented in the preceding Lecture, in regard to the properties of carbon and hydrogen, and the circumstances under which they are met with in nature,—it will readily occur to you that neither of these elementary bodies is likely to enter directly, or in a simple state, into the circulation of plants. The former (carbon) being a solid substance, and insoluble in water, cannot obtain admission into the pores of the roots, the only parts of the plants with which, in nature, it can come in contact. The latter, (hydrogen) does not occur either in the atmosphere or in the soil in any appreciable quantity, and hence, in its simple state, forms no part of the food of plants. Oxygen and nitrogen, again, both exist in the atmosphere in the gaseous state, and the former is known to be inhaled, under certain conditions, by the leaves of plants. Nitrogen may also in like manner be absorbed by the leaves of living plants, but, if so, it is in a quantity so small as to have hitherto escaped detection. The two latter substances (oxygen and nitrogen) are also slightly soluble in water, and, besides being inhaled by the leaves, may occasionally be absorbed in minute quantity along with the water taken in by the roots. But by far the largest proportion of these two elementary bodies, and the whole of the carbon and hydrogen which find their way into the interior of plants, have previously entered into a state of mutual combination —forming what are called distinct chemical compounds. Before describing the nature and constitution of these compounds, it will be proper to explain, 1°. the constitution of the atmosphere in which plants live, and, 2°. the nature of chemical combination and the laws by which it is regulated.

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* This will appear no way inconsistent with the statement in the former Lecture, that oxygen constitutes one-half by weight of all *living* plants, when it is recollected that of the water driven off in drying these plants, eight-ninths by weight consist of oxygen, and that 600 lbs. of grass, for example, yield only from 80 to 100 lbs of hay.

† Thus of the oak, the dried bark left 60 of ash—the dried leaves 53—the dried alburnum 4—and the dried wood only 2 parts in a thousand of ash.—*De Saussure.*

§ 4. *On the constitution of the atmosphere.*

The air we breathe, and in which plants live, is composed principally of a mixture of oxygen and nitrogen gases, in the proportion very nearly of 21 of the former to 79 of the latter. It contains, however, as a constituent necessary to the very existence of vegetable life, a small per centage of carbonic acid. On an average this carbonic acid amounts to about $\frac{1}{2500}$th part* of the bulk of the air. On the shores of the sea, or of great lakes, this quantity diminishes; and it becomes sensibly less as we recede from the land. It is also less by day than by night (as 3·38 to 4·32), and over a moist than over a dry soil.

The air is also imbued with moisture. Watery vapour is every where diffused through it, but the quantity varies with the season of the year, with the climate, with the nature of the locality, with its altitude, and with its distance from the equator. In temperate climates, it oscillates on the same spot between ½ and 1½ per cent. of the weight of the air; being least in mid-winter and greatest in the hot months of summer. There are also mingled with the atmosphere, traces of the vast variety of substances which are capable of rising from the surface of the earth in the form of vapour: such, for example, as are given off by decaying animal or vegetable matter—which are the produce of disease in either class of bodies—or which are evolved during the operations of nature in the inorganic kingdom, or by the artificial processes of man. Among these accidental vapours are to be included those miasmata, which, in certain parts of the world, render whole districts unhealthy,—as well as certain compounds of ammonia, which are inferred to exist in the atmosphere, because they can be detected in rain water, or in snow which has newly fallen.

In this constitution of the atmosphere we can discover many beautiful adaptations to the wants and structure of animals and plants. The exciting effect of pure oxygen on the animal economy is diluted by the large admixture with nitrogen; the quantity of carbonic acid present is sufficient to supply food to the plant, while it is not so great as to prove injurious to the animal;—and the watery vapour suffices to maintain the requisite moisture and flexibility of the parts of both orders of beings, without in general being in such a proportion as to prove hurtful to either.

The air also, by its subtlety, diffuses itself every where. Into every pore of the soil it makes its way. When there, it yields its oxygen or its carbonic acid to the dead vegetable matter or to the living root. A shower of rain expels the half-corrupted air, to be succeeded by a purer portion as the water retires. The heat of the sun warms the soil, and expands the imprisoned gases,—these partially escape, and are, as before, replaced by other air when the rays of the sun are withdrawn.

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* 0·04 per cent. The mean of 104 experiments made by Saussure at Geneva at all times of the year and of the day gave 4·15 volumes in 10000. The maximum was 5·74, and the minimum 3·15.

By the action of these and other causes a constant circulation is, to a certain extent, kept up,—between the atmosphere on the surface, which plays among the leaves and stems of plants, and the air which mingles with the soil and ministers to the roots. The precise effect and the importance of this provision will demand our consideration in a future lecture.

§ 5. *The nature and laws of chemical combination.*

The terms *combine* and *combination* in chemical language have a strict and precise application. If sand and saw-dust be rubbed together in a mortar they may be intimately intermingled, but by pouring water on the mass we can separate the particles of wood and leave the sand unchanged behind. So if we stir oatmeal and water together, we may cause them perfectly to mix together, but by the aid of a gentle heat we can expel the water and obtain dry oatmeal in its original condition. Or, by putting salt into water, it will dissolve and disappear, and form what is called a solution, but by boiling it down, as is done in our salt-pans, the water may be entirely removed and the salt procured of the weight originally employed and possessed of its original properties.

In none of these cases has any chemical action taken place, or any permanent change been produced, upon any of the substances. The two former were merely mixtures. *In all cases of chemical action a permanent change takes place in some of the substances employed;* and this change is the result either of a chemical *combination*, or of a chemical *decomposition*.

Thus when sulphur is burned in the air, it is converted into white vapours possessed of a powerful and very unpleasent odour, and which continue to be given off until the whole of the sulphur is dissipated.

Here a solid substance is permanently changed into noxious vapours which disappear in the air, and this change is caused by the combination of the sulphur with the oxygen of the atmosphere.

In like manner when limestone is put into a kiln and strongly heated or burned, it is changed or converted into quicklime—a substance very different in its properties from the natural limestone employed. But this is a case of chemical *decomposition*. The limestone consists of lime and carbonic acid. By the heat these are separated, the latter is driven off and the former remains in the kiln.

Again, when a jet of hydrogen gas is kindled in the air or in oxygen gas, it burns with a pale yellow flame. If a cold vessel be held over this flame, it speedily becomes bedewed with moisture, and drops of water collect upon it. How remarkable the change which hydrogen undergoes during this combustion! It unites with the oxygen of the atmosphere and forms water. How different in its properties is this water from either the oxygen or the hydrogen by the union of which it is formed! The former a liquid, the latter gases; the former an enemy to all combustion, while of the latter, the one (hydrogen) burns readily, the other (oxygen) is the very life and support of combustion in all other bodies.

1°. It appears, therefore, that chemical combination or decomposition is always attended by a permanent change.

2°. That when combination takes place a new substance is formed differing in its properties from any of these from which it was produced, or of which it consists.

When two or more elementary bodies thus unite together to form a new substance, this new substance is called a *chemical compound.* Thus water is a compound (not a mixture) of the two elementary bodies oxygen and hydrogen.

Now when such combination takes place, it is found to do so always in accordance with certain fixed laws. Thus:

I. Bodies unite together *only in constant and definite proportions*. We can *mix* together oxygen and hydrogen gases, for example, in any proportion, a gallon of the one with any number of gallons of the other, but if we burn two gallons of hydrogen gas in any greater number of gallons of oxygen, they will only consume or unite with one gallon of the oxygen, the rest of this gas ramaining unchanged. A quantity of water will be formed by this union, in which the whole of the hydrogen will be contained, combined with all the oxygen that has disappeared. Under no circumstances can we burn hydrogen so as to cause it to consume more oxygen, or from a given weight of hydrogen to produce more than a known weight of water. And as oxygen is nearly sixteen times heavier than nitrogen, it is obvious that one gallon of the former is about eight times heavier than two gallons of the latter, so that by weight these two gases, when thus burned, unite together nearly in the proportion of 1 to 8,—one pound of hydrogen forming nine pounds of water.

Again, when pure carbon is burned in the air, it unites with a fixed and constant weight of oxygen to form carbonic acid; it never unites with more, and it does not form carbonic acid when it unites with less.

Now this law of fixed and definite proportions is found to hold in regard to all bodies, and in all cases of chemical combination. Thus we have seen that—

By weight.		*By weight.*	
1 of hydrogen	combines with	8 of oxygen	to form water.
So 6 of carbon	combine	8	carbonic oxide.
and 14 of nitrogen		8	nitrous oxyde.

Hence 1 of hydrogan, 6 of carbon, and 14 of nitrogen unite respectively with the weight (8) of oxygen. These several numbers, therefore, are said to be *equivalent* to each other (they are *equivalent numbers*). Or they represent the fixed and definite proportions in which these several substances combine together (they are *definite proportionals*). Some chemists consider these numbers to represent the relative weights of the atoms or smallest particles of which the several substances are made up, and hence not unfrequently speak of them as the *atomic weights* of these substances, or more shortly *their atoms*.

For the sake of brevity, it is often useful to represent the simple or elementary bodies shortly by the initial letter of their names. Thus hydrogen is represented by H, carbon by C, and nitrogen by N, and these letters are used to denote not only the substances themselves, but that quantity which is recognised as its *equivalent*, *proportional*, or *atomic weight*. Thus:

Symbol.	*Equivalent or atomic weights.*	*Name.*
H	denotes 1 by weight, of	hydrogen.
C	6	carbon.
O	8	oxygen.
N	14[*]	nitrogen.

Chemical *combination* is expressed shortly by placing these letters in juxta-position, or sometimes in brackets, with the sign plus (+) between them. Thus H O or (H + O) denotes the combination of one atom or equivalent of hydrogen with one of oxygen, that is water; and at the same time a weight of water (9), equal to the sum of the atomic weights (1 + 8) of hydrogen and nitrogen.

A number prefixed or appended to a symbol, denotes that so many equivalents of the substance represented by the symbol are meant, as that number expresses. Thus 2 H O, 3 H O, or 3 (H + O), mean two or three equivalents of water, 3 H or H^3 three equivalents of hydrogen, and 4 C or C^4, 2 N or N^2, four of carbon and two of nitrogen respectively.

II. Not only are the *quantities* of the substances which unite together definite and constant, but the *properties* or *qualities* of the substances formed are in general equally so. The properties of pure water or of carbonic acid are constant and invariable under whatever circumstances they may be formed, and the elements of which they consist, when they combine together in the same proportions, are never known to form any other compounds but water and carbonic acid.

This law, however, though generally, is not universally true. Many substances are known which contain the same elements united together in the same proportions, and which, nevertheless, possess very different properties. Oil of turpentine and oil of lemons are in this condition. They both consist of the same elements, carbon and hydrogen, united together in the same proportions, and yet their sensible properties as well as their chemical relations* are very dissimilar.

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[*] More correctly 1, 6·13, 8·013, and 14·19.

Cane sugar, starch, and gum, all of them abundant products of the vegetable kingdom, consist also of the same elements, carbon, hydrogen, and oxygen, united together in the same proportions, and may even be represented by the same *formula* ($C^{12}\ H^{10}\ O^{10}$),† and yet these substances are as unlike to each other in their properties, as many bodies are of which the chemical composition is very different. To compounds thus differing in their properties, and yet containing the same elements, in the same proportions, chemists have given the name of *Isomeric bodies*, I shall have occasion to make you more familiar with some of them hereafter.

3°. Another important law by which chemical combinations are regulated, is known by the name of the law of *multiple proportions*. Some substances are observed to be capable of uniting together in more than one proportion. Thus carbon unites with oxygen in several proportions, forming carbonic oxide, carbonic acid, oxalic acid, &c. Now when such is the case, it is found that the quantity (the weight) of each substance which enters into the several compounds, if not actually represented by the equivalent number or atomic weight, is represented by some simple multiple of that number. Thus two equivalents of carbon unite with 2, 3, or 4 equivalents of oxygen, to form carbonic oxide, oxalic acid, and carbonic acid respectively,—while one of nitrogen unites with 1, 2, 3, 4, or 5 oxygen to form a series of compounds, of which the last ($N\ O^5$) nitric acid, is the only one I shall have frequent occasion to speak of in the present lectures.

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* By the chemical relations of a substance are meant the effects which are produced upon it by contact with other chemical substances.

† This *formula* means that starch, gum, and sugar, consist of 12 equivalents of carbon united to 10 of hydrogen and 10 of oxygen.

This law of multiple proportions, though of great importance in chemical theory, I do not further illustrate, as we shall have very little occasion to refer to it in the discussion of the several topics which will hereafter come before us.

Having thus briefly explained the nature and laws of chemical combination, I proceed to make you acquainted with those chemical compounds of the organic elements which are known or are supposed to minister to the growth of plants.

The number of compounds which the four organic elements form with each other is almost endless; but of this number a very few only are known to minister directly to the growth or nourishment of plants. Of these, water, carbonic acid, ammonia, and nitric acid, are the most important; but it will be necessary shortly to advert to a few others, of the occurrence or production or action of which we may hereafter have occasion to speak.

§ 6. *Of water and its relations to vegetable life.*

Water is a compound of oxygen and hydrogen in the proportion, as already stated, of 8 of the former to 1 of the latter by weight, or of 1 volume of oxygen to 2 of hydrogen.

It is more universally diffused throughout nature than any other chemical compound with which we are acquainted, performs most important functions in reference to animal and vegetable life, and is endowed with properties by which it is wonderfully adapted to the existing condition of things.

We are familiar with this substance in three several states of cohesion,—in the solid form as ice, in the fluid as water, and in the gaseous as steam. At 32° F. and at law temperature, it continues solid, at higher temperatures it melts and forms a liquid (water), which at 212° F. begins to boil and is converted into steam. By this change its bulk is increased 1700 times, and it becomes nearly two-fifths lighter than common air.* It therefore readily rises into and diffuses itself through the atmosphere.

I. There are only one or two circumstances in which water in the solid form materially affects or interferes with the labours of the agriculturist.

1°. During the frost of a severe winter, the soil contracts and appears to shrink in. But the water contained in its pores freezes and expands, and the minute crystals of ice thus formed separate the particles of the soil from each other. This expansion of the water in dry soils may not be equal to the natural contraction of the soil itself, yet still it is sufficient to cause a considerable separation of the earthy particles throughout the whole frozen mass. When a milder temperature returns, and a thaw commences, the soil expands and gradually returns to its former bulk, but the outer layers thaw first, and the particles being previously separated by the crystals of ice, and now loosened by the thaw, fall off or crumble down, and thus the soil becomes exposed to the mellowing action of the atmosphere which is enabled everywhere to pervade it. On heavy clay land this effect of the winter's frost not unfrequently proves very beneficial.†

2°. In the form of snow it has been often supposed to be beneficial to winter wheat and other crops. That a heavy fall of snow will shelter and protect the soil and crop from the destructive effects of any severe cold which may follow, there can be no doubt. It forms a light porous covering, by which the escape of heat from the soil is almost entirely prevented. It defends the young shoots also from these alternations of temperature to which the periodical return of the sun's rays continually exposes them;[*] and when a thaw arrives, by slowly melting, it allows the tender herbage gradually to accustom itself to the milder atmosphere.

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* Common air being 1, steam is 0·62.

† This alternate contraction and expansion is often injurious to the practical farmer in *throwing out* his winter wheat. Some varieties are said to be more thrown out than others, and this peculiarity is sometimes ascribed to the longer and stronger roots which shoot from one variety than from another; it may, however, be occasionally owing to the different nature of the soils in which the trials have been made, or when, in the same soil, to the different states of dryness at different times.

In this manner there is no doubt that a fall of snow may often be of great service to the practical farmer. But some believe that winter wheat actually *thrives* under snow. On this point I cannot speak from personal knowledge, but I will here mention two facts concerning snow, which may possibly be connected with its supposed nourishing quality.

In the first place, snow generally contains a certain quantity of ammonia, or of animal matter which gives off ammonia during its decay. This quantity is variable, and is occasionally so small as to be very difficult of detection. Liebig found it in the snow of the neighborhood of Giessen, and I have this winter detected traces of it in the snow which fell in Durham[†] during two separate storms. This ammonia is present in greater quantity in the first portions that fall and lie nearest the plant. Hence if the plant can grow beneath the snow, this ammonia may affect its growth; or when the first thaw comes it may descend to the root, and may there be imbibed. Rain water also contains ammonia, but when rain falls in large quantity it runs off the land, and may do less good than the snow, which lies and melts gradually.*

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[*] The effects of such alternations are seen on the occurrence of a night's frost in spring. If the sun's rays fall in the early morning, on a frozen shoot, it droops, withers, and blackens—it is destroyed by the frost. If the plant be in a shaded spot, where the sun does not reach it till after the whole atmosphere has been gradually heated, and the frozen tissue slowly thawed, its leaves sustain little injury, and the warmth of the sun's rays, instead of injuring, cherish and invigorate it. This effect of *sudden* alternations of temperature on organic matter explains many phenomena, to which it would here be out of place to advert.

A thick light covering of porous earth not beaten down preserves the potato pit from the effects of the frost better than a solid compact coating of clay, in the same way as snow protects the herbage better than a sheet of ice; and it is because of the porosity of the covering, that ice may be preserved more effectually, and for a longer period in a similar pit, than in many well constructed ice-houses.

[†] By adding two drops of sulphuric acid to four pints of snow water,

Another singular property of snow is the power it possesses of absorbing oxygen and nitrogen from the atmosphere, in proportions very different from those in which they exist in the air. The atmosphere, as already stated, contains 21 per cent. of oxygen by volume (or bulk), but the air which is present in the pores of snow has been found by various observers to contain a much smaller quantity. Boussingault† obtained from air disengaged by melting snow 17 per cent. of oxygen only, and De Saussure found still less. The difficulty of respiration experienced on very high mountains has been attributed to the nature of the air liberated from snow when melted by the sun's rays. Whether the air retained among the pores of the snow, which in severe winters covers our corn-fields, be equally deficient in oxygen with that examined by Boussingault, and whether, if it be, the abundance of nitrogen can at all affect vegetation, are matters that still remain undetermined.

II. In the fluid state, that of water, the agency of this compound in reference to vegetable life, though occasionally obscure, is yet every where discernible.

Pure water is a colourless transparent fluid, destitute of either taste or smell. It enters largely into the constitution of all living animals and plants, and forms upwards of one half of the weight of all the newly gathered vegetable substances we are in the habit of cultivating or collecting for the use of man.‡

Not only does it enter thus largely into the constitution of all animals and plants, but in the existing economy of nature its presence in large quantities is absolutely necessary to the persistence of animal and vegetable life. In the midst of abundant springs and showers, plants shoot

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evaporating to dryness, and mixing the dry mass with quicklime or caustic potash. The residual mass contained a brown organic matter mixed with the sulphate of ammonia.

* For the properties of ammonia, see Lecture III.

† Annalen der Physik (Poggendorf), xxxiv. p. 211.

‡ See page 33.

understand how indespensable it is to the continued fertility of the soil.

Nor is it merely earthy and saline substances which the water dissolves, as it thus percolates through the soil. It takes up also substances of organic origin, especially portions of decayed animal and vegetable matter,—such as are supposed to be capable of ministering to the growth of plants,—and brings them within reach of the roots.

This solvent power of water over solid substances is increased by an elevation of temperature. Warm water, for example, will dissolve Epsom salts or oxalic acid in much larger quantity than cold water will, and the same is true of nearly all solid substances which this fluid is capable of holding in solution. To this increased solvent power of the water they absorb, is ascribed, among other causes, the peculiar character of the vegetable productions, as well as their extraordinary luxuriance, in many tropical countries.

2°. But the *affinity* which water exhibits for many solid substances is little less important and remarkable.

When newly burned lime is thrown into a limited quantity of water the latter is absorbed, while the lime heats, cracks, swells, and finally falls into a white powder. When thus perfectly slaked, it is found to be one-third heavier than before—every three tons having absorbed one ton of water. This water is retained in a solid form, more solid than water is when in the state of ice, and it cannot be entirely separated from the lime without the application of a red heat. When you lay upon your land, therefore, four tons of slaked lime, you mix with your soil one ton of water, which the lime afterwards gradually gives up, either in whole or in part, as it combines with other substances. To this fact we shall return when we hereafter consider the various ways in which lime acts, when it is employed by the farmer for the purpose of improving his land.*

For clay also, water has a considerable affinity, though by no means equal to that which it displays for quicklime. Hence, even in well drained clay lands, the hottest summer does not entirely rob the clay of its water. It cracks, contracts, and becomes hard, yet still retains water enough to keep its wheat crops green and flourishing, when the herbage on lighter soils is drooping or burned up.

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* See the subsequent lecture, "*On the action of lime when employed as a manure.*"

A similar *affinity* for water is one source of the advantages which are known to follow from the admixture of a certain amount of vegetable matter with the soil; though, as in the case of charcoal, its porosity* is probably more influential in retaining moisture near the roots of the plants.†

3°. The degree of affinity by which the elements of water are held together, exercises a material influence on the growth and production of all vegetable substances.

If I burn a jet of hydrogen gas in the air, *water is formed* by the union of the hydrogen with the oxygen of the atmosphere, for which it manifests on many occasions an apparently powerful affinity. But if into a vessel of water I put a piece of iron or zinc and then add sulphuric acid, the *water is decomposed* and the hydrogen set free, while the metal combines with the oxygen.

So in the interior of plants and animals, water undergoes continual *de*composition and *re*composition. In its fluid state, it finds its way and exists in every vessel and in every tissue. And so slight, it would appear, in such situations, is the hold which its elements have upon each other—or so strong their tendency to combine with other substances, that they are ready to separate from each other at every impulse—yielding now oxygen to one, and now hydrogen to another, as the production of the several compounds which each organ is destined to elaborate respectively demands. Yet with the same readiness do they again re-attach themselves and cling together, when new metamorphoses require it. It is in the form of water, indeed, that nature introduces the greater portion of the oxygen and hydrogen which perform so important a part in the numerous and diversified changes which take place in the interior of plants and animals. Few things are really more wonderful in chemical physiology, than the vast variety of transmutations which are continually going on, through the agency of the elements of water.

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* *Affinity* for water causes a vegetable matter to combine chemically with it, *porosity* causes it merely to drink in the water mechanically, and to retain it, *unchanged*, in its pores.

† For an exposition of the intimate relation of water to the chemical constitution of the solid parts of living vegetable, see a subsequent Lecture, "*On the nature and production of the substances of which plants chiefly consist.*"

III. In the state of vapour water ministers most materially to the life and growth of plants. It not only rises into the air at 212° Fhr. when it begins to boil, but it disappears or evaporates from open vessels at almost every temperature, with a rapidity proportioned to the previous dryness of the air, and the velocity and temperature of the atmospheric currents which pass over it. Even ice and snow are gradually dissipated in the coldest weather, and sometimes with a degree of velocity which at first sight seems truly surprising.*

It thus happens that the atmosphere is constantly impregnated with watery vapour, which in this gaseous state accompanies the air wherever it penetrates, permeates the soil, pervades the leaves and pores of plants, and gains admission to the lungs and general vascular system of animals. We cannot appreciate the influence which, in this highly comminuted form, water exercises over the general economy of organic nature.

But it is chiefly when it assumes the form of rain and dew, and re-descends to the earth, that the benefits arising from a previous conversion of the water into vapour become distinctly appreciable. The quantity of vapour which the air is capable of holding in suspension is dependent upon its temperature. At high temperatures, in warm climates, or in warm weather, it can sustain more—at low temperatures less. Hence when a current of comparatively warm air loaded with moisture ascends to or comes in contact with a cold mountain top, it is cooled down, is rendered incapable of holding the whole of the vapour in suspension, and therefore leaves behind in the form of a mist or cloud, a portion of its watery burden. In rills subsequently, or springs, the aqueous particles which float in the midst, reappear on the plains beneath, bringing nourishment* at once, and a grateful relief to the thirsty soil.

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* Mr. Howard states that a circular patch of snow 5 inches in diameter lost in the month of January 150 grains of vapour between sunset and sunrise, and 56 grains more before the close of the day, when exposed to a smart breeze on a house-top. From an acre of snow this would be 1000 gallons of water during the night only.—*Prout's Bridgewater Treatise, p.* 302; *Encyclopæd. Metropol. Art. Meteorology.*

In Von Wrangell's account of his visit to Siberia and the polar sea, translated by Major Sabine (p. 390), it is stated that, in the intense cold, not only living bodies—but the very *snow—smokes* and fills the air with vapour.

So when two currents of air charged with moisture, but of unequal temperature, meet in the atmosphere, they mix, and the mixture has the mean temperature of the two currents. But air of this mean temperature is incapable of holding in suspension the mean quantity of watery vapour; hence, as before, a cloud is formed, and the excess of moisture falls to the earth in the form of rain. In descending to refresh the earth, this rain discharges in its progress another office. It washes the air as it passes through it, dissolving and carrying those accidental vapours which, though unwholesome to man, are yet fitted to minister to the growth of plants.

The dew, celebrated through all times and in every tongue for its sweet influence, presents the most beautiful and striking illustration of the agency of water in the economy of nature, and exhibits one of those wise and bountiful adaptations, by which the whole system of things, animate and inanimate, is fitted and bound together.

All bodies on the surface of the earth radiate, or throw out rays of heat, in strait lines—every warmer body to every colder; and the entire surface is itself continually sending rays upwards through the clear air into free space. Thus on the earth's surface all bodies strive, as it were, after an equal temperature (an equilibrium of heat), while the surface as a whole tends gradually towards a cooler state. But while the sun shines this cooling will not take place, for the earth then receives in general more heat than it gives off, and if the clear sky be shut out by a canopy of clouds, these will arrest and again throw back a portion of the heat and prevent it from being so speedily dissipated. At night, then, when the sun is absent, the earth will cool the most; on clear nights also more than when it is cloudy, and when clouds only partially obscure the sky, those parts will become coolest which look towards the clearest portions of the heavens.

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* For the nature of this *nourishment* see the subsequent Lectures, "*On the inorganic constituents of plants.*"

Now when the surface cools, the air in contact with it must cool also; and like the warm currents on the mountain side, must forsake a portion of the watery vapour it has hitherto retained. This water, like the floating mist on the hills, descends in particles almost infinitely minute. These particles collect on every leaflet, and suspend themselves from every blade of grass, in drops of "pearly dew."

And mark here a beautiful adaptation. Different substances are endowed with the property of radiating their heat, and of thus becoming cool with different degrees of rapidity, and those substances which in the air become cool first, also attract first and most abundantly the particles of falling dew. Thus in the cool of a summer's evening the grass plot is wet, while the gravel walk is dry; and the thirsty pasture and every green leaf are drinking in the descending moisture, while the naked land and the barren highway are still unconscious of its fall.

How beautiful is the contrivance by which water is thus evaporated or distilled as it were into the atmosphere—largely perhaps from some particular spots,—then diffused equably through the wide and restless air,—and afterwards precipitated again in refreshing showers or in long-mysterious dews![*] But how much more beautiful the contrivance, I might almost say the instinctive tendency, by which the dew selects the objects on which it delights to fall; descending first on every living plant, copiously ministering to the wants of each, and expending its superfluity only on the unproductive waste.

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[*] The beauty of this arrangement appears more striking when we consider that the whole of the watery vapour in the air, if it fell at once in the form of rain, would not amount to more than 5 inches in depth on the whole surface of the globe. In England the fall of rain varies from 22 inches (London, York, and Edinburgh) to 68 (Keswick), while in some few parts of the world (St. Domingo) it amounts to as much as 150 inches. The mean fall of rain over the whole earth is estimated at 32 or 33 inches; but if we suppose it to be only 10 or 15 inches, the water which thus falls will require to be two or three times re-distilled in the course of every year. This is exclusive of dew, which in many countries amounts to a very large quantity—See *Prout's Bridgewater Treatise*, p. 309.

And equally kind and bountiful, yet provident, is nature in all her operations, and through all her works. Neither skill nor materials are ever wasted; and yet she ungrudgingly dispenses her favours, apparently without measure, —and has subjected dead matter to laws which compel it to minister, and yet with a most ready willingness, to the wants and comforts of every living thing.

And how unceasingly does she press this her example not only of unbounded goodness, but of universal charity—above all other men—on the attention of the tiller of the soil. Does the corn spring more freshly when scattered by a Protestant hand—are the harvests more abundant on a Catholic soil,—and does not the sun shine alike, and the dew descend, on the domains of each political party?

So science, from her daily converse with nature, fails not sooner or later to take her hue and colour from the perception of this universal love and bounty. Party and sectarian differences dwindle away and disappear from the eyes of him who is daily occupied in the contemplation of the boundless munificence of the great Impartial; he sees himself standing in one common relation to all his fellow-men, and feels himself to be most completely performing his part in life, when he is able in any way or in any measure to contribute to the general welfare of all.

It is in this sense too that science, humbly tracing the footsteps of the Deity in all his works, and from them deducing his intelligence and his universal goodness—it is in this sense, that science is of no sect, and of no party, but is equally the province, and the property, and the friend of all.

§ 7. *Of the cold produced by the evaporation of water, and its influence on vegetation.*

Beautiful, however, and beneficent as are the provisions by which, in nature, watery vapour is made to serve so many useful purposes, there are circumstances in which, and often through the neglect of man, the presence of water becomes injurious to vegetation.

The ascent of water, in the form of vapour, permits the soil to dry, and fits it for the labors of the husbandman; while its descent in dew refreshes the plant, exhausted by the heat and excitement of a long summer's day. But the same tendency to ascend in vapour, gives rise to the cold unproductive character of lands in which water is present in great excess. This character you are familiar with in what are called *cold clay* soils.

The epithet *cold*, applied to such soils, though derived probably from no theoretical views, yet expresses very truly their actual condition. The surface of the fields in localities where such lands exist, is in reality less warm, throughout the year, than that of fields of a different quality, even in their immediate neighborhood. This is readily proved, by placing the bulb of a thermometer immediately beneath the soil in two such fields, when in the hottest day a marked difference of temperature will, in general, be perceptible. The difference is dependant upon the following principle :—

When an open pan of water is placed upon the fire, it continues to acquire heat till it reaches the temperature of 212° F. It then begins to boil, but *ceases to become hotter*. Steam, however, passes off, and the water diminishes in quantity. But while the vessel remains upon the fire the water continues to receive heat from the burning fuel as it did before it began to boil. But since, as already stated, it becomes no hotter, the heat received from the fire must be carried off by the steam.

Now this is universally true. *Whenever water is converted into steam, the ascending vapour carries off much heat along with it.*

This heat is not missed, or its loss perceived, when the vapour or steam is formed over a fire; but let water evaporate in the open air from a stone, a leaf, or a field, and it must take heat with it from these objects—and the surface of the stone, the leaf, or the field, must become colder.

That stone or leaf also must become coldest from which the largest quantity of vapour rises.

Now, let two adjoining fields be wet or moist in different degrees, that which is wettest will almost at all times give off the largest quantity of vapour, and will therefore be the coldest. Let spring arrive, and the genial sun will gently warm the earth on the surface of the one, while the water in the other will swallow up the heating rays, and cause them to re-ascend in the watery vapour. Let summer come, and while the soil of the one field rises at mid-day to perhaps 100° F. or upwards, that of the other may, in ordinary seasons, rarely reach 80° or 90°—in wet seasons may not even attain to this temperature, and only in long droughts will derive the full benefit of the solar rays. I shall hereafter more particularly advert to the important influence which a high temperature in the soil exercises over the growth of plants, the functions of their several parts, and their power of ripening seeds—as well as to certain beautiful adaptations by which nature, when left to herself, is continually imparting to the soil, especially in northern latitudes, those qualities which fit it for deriving the greatest possible benefit from the presence of the sun's rays. In the mean time you are willing to concede that warmth in the soil is favourable to the success of your agricultural pursuits. What, then, is the cause of the coldness and poverty, the fickleness and uncertainty of produce in land of the kind now alluded to? It is the presence of too much water. What is the remedy? A removal of the excess of water. And how? By effectual drainage.

There are other benefits to the land, which follow from this removal of the excess of water by draining, of which it would here be out of place to treat; but a knowledge of the above principle shows you that the first effect upon the soil is the same as if you were to place it in a warmer climate, and under a milder sky—where it could bring to maturity other fruits, and yield more certain crops.

The application of this merely rudimentary knowledge will enable you to remove from many improvable spots the stigma of being *poor* and *cold*; an appellation hitherto applied to them,—not because they are by nature unproductive, but because ignorance, or indolence, or indifference, has hitherto prevented their natural capabilities from being either appreciated or made available.

Note.—In reference to the supposed fertilizing effect of snow, adverted to in the above lecture, I may mention a fact observed by Heyer, and quoted by Liebig (p. 125), that willow branches immersed in snow water put forth roots three or four times longer than when put into pure distilled water, and that the latter remained clear while the snow water became coloured. This shows that snow contains something not present in distilled water, which is capable of accelerating the growth of plants. The experiment would have been more instructive in regard to natural operations, had the effect of the snow water been compared with that of an equal bulk of rain water, collected under similar circumstances.

LECTURE III.

Carbonic and oxalic acids, their properties and relations to vegetable life—Carbonic oxide and light carburetted hydrogen, their properties and productions in nature—Ammonia, its properties and relations to vegetable life.

§ 1. *Carbonic acid, its properties and relations to vegetable life.*

When charcoal is burned in the air it combines slowly with oxygen, and is transformed into carbonic acid gas. In oxygen gas it burns more rapidly and vividly, producing the same compound.

This gas is colourless, like oxygen, hydrogen, and nitrogen, but is readily distinguished from all these, by its acid taste and smell, by its solubility in water, by its great density, and by its reddening vegetable blues. Water at 60 F. and under the ordinary pressure of the atmosphere, dissolves rather more than its own bulk of this gas (100 dissolve 106), and however the pressure may be increased, it still dissolves the same bulk.

All gases diminish in bulk uniformly as the pressure to which they are subjected is increased. Thus under a pressure of two atmospheres they are reduced to one-half their bulk, of three atmospheres to one-third, and so on. When water, therefore, is saturated with carbonic acid under great pressure, as in the manufacture of soda water, though it still dissolves only its own bulk, yet it retains a weight of the gas which is proportioned to the pressure applied. For the same reason also, when the pressure is removed, as in drawing the cork from a bottle of water so impregnated, the gas expands and escapes, causing a lively effervescence, and the water retains only its own bulk at the existing pressure. This solution in water has a slightly sour taste, and reddens vegetable blues. These properties it owes to the presence of the gas, which is therefore what chemists call an *acid*[*] body, and hence its name of carbonic *acid*.

This gas is one-half heavier than atmospheric air, its density being 1.524, and hence it may be poured through the air from one vessel to another. Hence also, when it is evolved from crevices in the earth, in caves, in wells, or in the soil, this gas diffuses itself through the atmosphere and ascends into the air, much more slowly than the elementary gases described in the previous lecture. Where it issues from the earth in large quantity, as in many volcanic districts, it flows along the surface like water, enters into and fills up cracks and hollows, and sometimes reaches to a considerable distance from its source, before it is lost among the still air.

Burning bodies are extinguished in carbonic acid, and living beings, plunged into it, instantly cease to breathe. Mixed with one-ninth of its bulk of this gas the atmospheric air is rendered unfit for respiration. It is, however, the principal food of plants, being absorbed by their leaves and roots in large quantity. Hence the presence of carbonic acid in the atmosphere is necessary to the growth of plants, and they have been observed to thrive better when the quantity of this gas in the air is considerably augmented. Common air, as has been already stated, does not contain more on an average than $\frac{1}{2500}$th of its bulk of carbonic acid, but De Saussure found that plants *in the sunshine* grew better when it was increased to $\frac{1}{12}$th of the bulk of the air, but beyond this quantity they were injured by its presence, even when exposed to the sun. When the carbonic acid amounted to one-half, the plants died in seven days; when it reached two-thirds of the bulk of the air, they ceased to grow altogether. In the shade any increase of carbonic acid beyond that which naturally exists in the atmosphere of our globe, was found to be injurious.

These circumstances it is of importance to remember. Did the sun *always shine* on every part of the earth's surface, the quantity of carbonic acid in the atmosphere might probably have been increased with advantage to vegetation. But every such increase would have rendered the air less fit for the respiration of existing races of animals. Thus we see that not only the nature of living beings, both plants and animals, but also the periodical absence of the sun's rays, have been taken into account in the present arrangement of things.

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[*] Acids have generally a sour taste, redden vegetable blues, or combine with *bases* such as lime, soda, potash, &c., to form *salts*.

In perpetual sunshine plants would flourish more luxuriantly in air containing more carbonic acid, but they would droop and die in the shade. This is one of those proofs of *unity of design* which occasionally force themselves upon our attention in every department of nature, and compel us to recognise the regulating superintendence of *one mind.* The same hand which mingled the ingredients of the atmosphere, also set the sun to rule the day *only,*—tempering the amount of carbonic acid to the time of his periodical presence, as well as to the nature of animal and vegetable life.

Carbonic acid consists of one equivalent of carbon and two of oxygen, and is represented by $C\,O^2$. It unites with bases (potash, soda, lime, &c.), and forms compounds known by the name of *carbonates.* Thus *pearlash* is an impure *carbonate of potash,*—the common soda of the shops, *carbonate of soda,*—and limestone or chalk, *carbonate of lime.* From these compounds it may be readily disengaged by pouring upon them diluted muriatic or sulphuric acids. From limestone it is also readily expelled by heat, as in the common lime-kilns. During this process the limestone loses nearly 44 per cent.* of its weight, a loss which represents the quantity of carbonic acid driven off.†

Common carbonate of lime, in its various forms of chalk, hard limestone, or marble, is nearly insoluble in water, but it dissolves readily in water containing carbonic acid. Thus, if a current of this gas be passed through lime-water, the liquid speedily becomes milky from the formation and precipitation of carbonate of lime, but after a short time the cloudiness disappears, and the whole of the lime is re-dissolved. The application of heat to this clear solution expels the excess of carbonic acid, and causes the carbonate of lime again to fall.

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* 43·7 when pure and dry.

† Hence by burning limestone on the spot where it is quarried, nearly one-half of the cost of transport is saved.

By exposure to the air, we have already seen that water always absorbs a quantity of carbonic acid from the atmosphere. As it afterwards trickles through the rocks or through soil containing lime, it gradually dissolves a portion of this earth, equivalent to the quantity of gas it holds in solution, and thus reaches the surface impregnated with calcareous matter. Or it carries it in its progress below the surface to the roots of plants, where its earthy contents are made available, either directly or indirectly, to the promotion of vegetable growth. To the lime thus held in solution, spring and other waters generally owe their *hardness*, and it is the expulsion of the carbonic acid, by heat, that causes the deposition of the sediment so often observed when such waters are boiled.

I propose hereafter to devote an entire lecture to the consideration of the action of lime upon land, as it is employed for agricultural purposes, but I may here remark, that this solvent action of the carbonic acid in rain water is one of the principal agents in removing the lime from your soils, and in rendering a fresh application necessary after a certain lapse of time. It is the cause also of that deposit of calcareous matter at the mouths of drains, which you not unfrequently see in localities where lime is laid abundantly upon the land. The greater the quantity of rain, therefore, which falls in a district, the less permanent will be the effects of liming the land—the sooner will it be robbed of this important element of a fertile soil. Still carbonic acid is only one of several agents which act almost unceasingly in thus removing the lime from the land, a fact I shall hereafter have occasion more fully to explain.

In nature, carbonic acid is produced under a great variety of circumstances. It is given off from the lungs of all animals during respiration. It is formed during the progress of fermentation. Fermented liquors owe their sparkling qualities to the presence of this gas. During the decay of animal and vegetable substances in the air, in compost heaps, or in the soil, it is evolved in great abundance. In certain volcanic countries it issues in large quantity from springs and from cracks and fissures in the surface of the earth; while the vast amount of carbon contained in the wood and coal daily consumed by burning, is carried up into the atmosphere, chiefly in the form of carbonic acid. We shall hereafter consider the relation which exists between these several sources of supply and the proportion of carbonic acid permanently present in the air and so necessary to the support of vegetable life.

§ 2. *Oxalic acid, its properties and relations to vegetable life.*

Oxalic acid is another compound of carbon and oxygen, which, though not known to minister either to their growth or nourishment, is yet found largely in the interior of many varieties of plants. In an uncombined state it exists in the hairs of the chick pea. In combination with potash it is found in the wood sorrel (oxalis acetosella), in the common sorrel, and other varieties of *rumex*,—in which it is the cause of the acidity of the leaves and stems,—in the roots of these plants also, in the leaves and roots of rhubarb, and in the roots of tormentilla, bistort, gentian, saponaria, and many others. It is this combination with potash, formerly extracted from wood sorrel, which is known in commerce by the name of *salt of sorrel.* In combination with lime it forms the principal solid parts of many lichens, especially of the *parmeliæ* and *variolariæ*,* some of which contain as much oxalate of lime as is equivalent to 15 or 20 parts of pure acid in 100 of the dried plant.

The crystallized oxalic acid of the shops forms transparent colourless crystals, of an intensely sour taste. These crystals dissolve readily in twice their weight of cold water, and the solution, when sufficiently dilute, is agreeably acid to the taste. This acid is exceedingly poisonous. Half an ounce of the crystals is sufficient to destroy life in a very short time, and a quarter of an ounce after the lapse of a few days. It consists solely of carbon and oxygen in the proportion of two equivalents of the former to three of the latter. Its symbol is C^2O^3. It combines with bases, and forms salts which are known by the name of *oxalates*, and it is characterized by the readiness with which it combines with lime to form *oxalate of lime*. If a solution of the acid be poured into lime water, the mixture immediately becomes milky from the formation of this compound, which is insoluble in water.* It is this *oxalate of lime* which xists in the lichens, while *oxalate of potash* exists in the orrels.

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* The *parmelia cruciata* and *variolaria communis* are mentioned as peculiarly rich in this acid, which used to be extracted from them for sale. A species of parmelia, collected after the droughts on the sands of Persia and Georgia, contains 66 per cent. of oxalate of lime, with about 23 per cent. of a gelatinous substance similar to that obtained from Iceland moss. This lichen is used for food by the Kirghuis. A similar lichen is collected about Bagdad for a similar purpose.

Oxalic acid is one of those compounds of organic origin which we cannot form, as we can form carbonic acid by the direct union of its elements. In all our processes for preparing it artificially, we are obliged to have recourse to a substance previously *organized* in the living plant. It may be prepared from sugar, starch, or even from wood, by various chemical processes. The usual method is to digest potato starch with five times its weight of strong nitric acid (aquafortis), diluted with ten of water, till red fumes cease to be given off, and then to evaporate the solution. The oxalic acid separates in crystals, or, as it is usually expressed, *crystallizes* in the solution thus concentrated by evaporation.

It is not known to exist in the soil or in the waters which reach the roots of plants. Where it is found in living vegetables, therefore, it must, like the other substances they contain, have been formed or elaborated in the interior of the plant itself. By what very simple changes the production of this acid is or may be effected, we shall see in a subsequent lecture.

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* Substances that are insoluble are generally without action on the animal economy, and may be introduced into the stomach without producing any injurious effect. Hence this oxalate of lime, though it contains oxalic acid, is not poisonous. Hence also, if oxalic acid be present in the stomach, its poisonous action may be taken away by causing lime water or milk of lime to be swallowed in sufficient quantity. The acid combines with the lime, as in the experiment described in the text, and forms insoluble oxalate of lime. The common magnesia of the shops will serve the same purpose, forming an insoluble *oxalate of magnesia*. It is by performing experiments under circumstances where the results are visible—as in glass vessels—that we are enabled to predict the results in circumstances where the phenomena are not visible, and to act with as much confidence as if we could really see them.

§ 3. *Carbonic oxide, its constitution and properties.*

When carbonic acid (CO^2) is made to pass through a tube containing red-hot charcoal, it undergoes a remarkable change. Its gaseous form remains unaltered, but it combines with a second equivalent of carbon (becoming C^2O^2), which it carries off in the aeriform state. The new gas thus produced is known by the name of carbonic oxide. It consists of one equivalent of carbon united to one of oxygen, and is represented by $C^2\,O^2$, or simply $C\,O$.

This gas is colourless, without taste or smell, lighter than common air, nearly insoluble in water, extinguishes flame, does not support life; burns in the air or in oxygen gas with a blue flame, and during this combustion is converted into carbonic acid. It is produced along with carbonic acid during the imperfect combustion of coals in our fires and furnaces, but is not known to occur in nature, or to minister directly to the growth of plants.

There exists a general relation among the three compounds of carbon and oxygen above described, to which it may be interesting to advert, in connection with the subject of vegetable physiology. This relation appears when we compared together their chemical constitution, as represented by their chemical formulæ :—

Carbonic acid consists of one of carbon and two of oxygen, or CO^2;

Carbonic oxide, of one of carbon and one of oxygen, or CO;

So that if carbonic acid be present in a plant, and be there deprived of one equivalent of its oxygen, by any vital action, it will be converted into carbonic oxide.

Oxalic acid consists of two of carbon and three of oxygen, or C^2O^3.

If we add together the formulæ for

$$\begin{array}{ll} \text{Carbonic acid} & = CO^2 \text{ and} \\ \text{Carbonic oxide} & = CO, \text{ we have} \\ \hline \text{Oxalic acid} & = C^2O^3. \end{array}$$

Hence this acid may be formed in the interior of plants, either by the direct union of carbonic oxide and carbonic acid, or by depriving two of carbonic acid ($2\ CO^2$ or C^2O^4) of one equivalent of oxygen.

When in a subsequent lecture we have studied the structure and functions of the leaves of plants, we shall see how very easy it is to understand the process by which oxalic acid is formed and deposited in the interior of plants, and by which carbonic oxide also *may be*, and probably is, produced.

§ 4. *Light carburetted hydrogen—the gas of marshes and of coal mines.*

During the decay of vegetable matter in moist places, or under water, a light inflammable gas is not unfrequently given off, which differs in its properties from any of those hitherto described. In summer it may often be seen rising up in bubbles from the bottom of stagnant pools and from marshy places, and may readily be collected.

This gas is colourless, without taste or smell, and is little more than half the weight of common air.* A lighted taper, plunged into it, is immediately extinguished, while the gas takes fire and burns with a pale yellow flame, yielding more light, however, than pure hydrogen gas, which it otherwise resembles. Animals introduced into it instantly cease to breathe.

It consists of one equivalent of carbon (C) united to two of hydrogen ($2\ H$ or H^2), and is represented by CH^2.

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* Its specific gravity, by experiment, is 0·5576.

When burned in the air or in oxygen gas, the carbon it contains is converted into carbonic acid (CO^2), and the hydrogen into water (HO).

Like oxalic acid this gas cannot, by any known process, be produced from the direct union of the carbon and hydrogen of which it consists. It is readily obtained, however, by heating acetate* of potash in a retort, with an equivalent proportion of caustic baryta.

In nature it is largely evolved in coal mines, and is the principal combustible ingredient in those explosive atmospheres which so frequently cause disastrous accidents in our mining districts.

This gas is also given off along with carbonic acid during the fermentation of compost heaps, or of other large collections of vegetable matter. It is said also to be generally present in well manured soils,† and is supposed by many to contribute in such cases to the nourishment of plants. It is, however, very sparingly soluble in water, so that in a state of solution, it cannot enter largely into the pores of the roots, even though it be abundantly present in the soil. How far it can with propriety be regarded as a general source of food to plants, will be considered in the following lecture.

§ 5. *Ammonia, its properties and relations to vegetable life.*

Ammonia is a compound of hydrogen and nitrogen. It is possessed of many interesting properties, and is supposed to perform a very important part in the process of vegetation. It will be proper, therefore, to illustrate its nature and properties with considerable attention.

Ammonia, like the nitrogen and hydrogen of which it is composed, is a colourless gas, but, unlike its elements, is easily distinguished from all other gaseous substances by its smell and taste.

It possesses a powerful penetrating odour (familiar to you in the smell of hartshorn and of common smelling salts), has a burning acrid alkaline* taste, extinguishes a lighted taper as hydrogen and nitrogen do, but does not itself take fire like the former. It instantly suffocates animals, kills living vegetables, and gradually destroys the texture of their parts.

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* *Acetate* of potash is prepared by pouring vinegar (acetic acid) on common pearlash and evaporating the solution.

† Persoz, *Chimie Moleculaire*, p. 547.

It is absorbed in large quantities by porous substances, such as charcoal—which as already stated, absorbs 95 times its own bulk of ammoniacal gas. Porous vegetable substances in a decaying state likewise absorb it. Porous soils also, burned bricks, burned clay, and even common clay and iron ochre, which are mixed together on the surface of most of our fertile lands—all these are capable of absorbing or drinking in, and retaining within their pores, this gaseous substance, when it happens to be brought into contact with them.

But the quantity absorbed by water is much greater and more surprising. If the mouth of a bottle filled with this gas be immersed in water, the latter will rush up and fill the bottle almost instantaneously; and if a sufficient supply of ammonia be present, a given quantity of water will take up as much as 670 times its bulk of the gas.

This solution of ammonia in water is the spirit of hartshorn of the shops. When *saturated*† it is lighter‡ than pure water, has the pungent penetrating odour of the gas, and its hot, burning, alkaline taste—is capable of blistering the skin, and decomposing or destroying the texture of animal and vegetable substances.

You will remark here the effect which combination has in investing substances with new characters. The two gases hydrogen and nitrogen, themselves without taste or smell, and absorbed by water in minute quantity only, form by their union a compound body remarkable both for taste and smell, and for the rapidity with which water absorbs it.

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* The term *alkaline*, as applied to taste, will be best understood by describing it as a taste similar to that of the common soda and pearlash of the shops.

† That is, when gas is supplied till the water refuses to take up any more.

‡ Its specific gravity is 0·875, water being 1.

Ammonia possesses also alkaline properties,* it restores the blue colour of vegetable substances that have been reddened by an acid, and it combines with acid substances to form salts.

Among gaseous substances, therefore, there are some which, like carbonic acid, have a sour taste and redden vegetable blues; others which, like ammonia, have an alkaline taste and restore the blue colour; and a third class which, like oxygen, hydrogen, and nitrogen, are destitute of taste and do not affect vegetable colours. These last are called *neutral* or indifferent substances.

Ammonia, as above stated, combines with acids and forms salts, which at the ordinary temperature of the atmosphere are all solid substances. Hence if carbonic acid gas be mixed with ammoniacal gas, a white cloud is formed consisting of minute particles of solid *carbonate* of *ammonia*—the smelling salts of the shops. Hence also a feather dipped into vinegar or dilute muriatic acid (spirit of salt), and then introduced into ammoniacal gas, forms a similar white cloud, and becomes covered with a white down of solid *acetato* or of *muriate* of ammonia (sal ammoniac). The same appearance is readily seen by holding the feather to the mouth of a bottle containing hartshorn (liquid ammonia), from which ammoniacal gas continually escapes, and by its lightness rises into the air, and thus comes in contact with the acid upon the feather.

The fact of the production of a solid body by the union of two gases (ammonia and carbonic or muriatic acid gases) is one of a very interesting nature to the young chemist, and presents a further illustration of the *changes* resulting from chemical combination as explained in the previous lecture.

Ammonia is little more than half the weight of common air,[*] hence when liberated on the earth's surface it readily rises into and mingles with the atmosphere. It consists of hydrogen and nitrogen united together in the proportion of three equivalents[†] of hydrogen ($3\,H$ or H^3) and one of nitrogen (N), and hence it is represented by the symbol ($N + 3\,H$), or more shortly by NH^3. 100 parts by weight contain 82½ of nitrogen and 17½ of hydrogen.[‡]

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* In the previous lecture, the term *acid* was explained as applying to substances possessed of a sour taste, and capable of reddening vegetable blues, or combining with *bases* (potash, soda, magnesia, &c.) to form *salts*; *alkalies* are such as possess an alkaline taste (see previous Note), restore the blue colour to reddened vegetable substances, or combines with *acids* to form *salts*. Of salts, nitrate of soda, saltpetre (nitrate of potash), and glauber salts (sulphate of soda), are examples.

In nature, ammonia exists in considerable quantity. It is widely, almost universally, diffused, but is not known to form large deposits on any part of the earth's surface, or to enter as a constituent into any of the great mineral masses of which the crust of the globe is composed. It exists most abundantly in a *state of combination*—in the forms, for example, of muriate (sal ammoniac), of nitrate, and of carbonate of ammonia. It frequently escapes into the atmosphere in an uncombined state, especially where animal matters are undergoing decay, but it rarely exists in this free state for any length of time. It speedily unites with the carbonic acid of the air, with one or other of the numerous acid vapours which are continually rising from the earth, or with the nitric acid which is formed at the expense of the nitrogen and oxygen of which the atmosphere consists.

The influence of ammonia on vegetation appears to be of a very powerful kind. It seems not only to promote the rapidity and luxuriance of vegetation, but to exercise a powerful control over the functions of vegetable life. In reference to the nature and extent of this action, into which we shall hereafter have occasion to inquire, there are several special properties of ammonia which it will be of importance for us previously to understand.

1°. It has a powerful affinity[§] for acid substances. Hence the readiness with which it unites with acid vapours when it rises into the atmosphere. Hence also when formed or liberated in the soil, in the fold-yard, in the stable, or in compost heaps, it unites with such acid substances as may be present in the soil, &c., and forms saline compounds or *salts*. All these salts appear to be more or less influential in the processes of vegetable life.

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[*] More nearly three-fifths, its specific gravity being 0·59, that of air being 1.

[†] See second Lecture.

[‡] Correctly 82·545 and 17·455, respectively.

[§] By *affinity* is meant the tendency which bodies have to unite and to

2°. Yet this affinity is much less strong than that which is exhibited for the same acids by potash, soda, lime, or magnesia. Hence if any of these substances be mixed or brought into contact with a salt of ammonia, the acid of the latter is taken up by the potash or lime, while the ammonia is separated in a gaseous state. Thus when sal ammoniac in powder is mixed with twice its weight of quicklime, ammoniacal gas is liberated in large quantity. This is the method by which pure ammonia is generally prepared; and one of the *many* functions performed by lime when employed for the improvement of land, especially on soils rich in animal and vegetable matter, is that of decomposing the salts, especially the organic salts, of ammonia,—as will be more fully explained when we come to treat at length of this important part of agricultural practice.*

3°. The salts which ammonia forms with the acids are all, like ammonia itself, very soluble in water. Hence two consequences follow. First, that which rises into the air in the form of gas, and there combines with the carbonic or other acids, is readily dissolved, washed out and brought to the earth again by the rains and dews; so that at the same time the air is purified for the use of animals, and the ammonia brought down for the use of plants. And second, whatever salts of ammonia are contained in the soil, being dissolved by the rain, are in a condition to be taken up,

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remain united or combined. Thus ammonia forms a solid substance with the vapour of vinegar the moment the two substances come into contact; they have, therefore, a strong tendency to unite, or an *affinity* for each other.

* See Lecture "*On the use of lime.*" Owing to this property the action of lime upon compost heaps is often injurious, by causing the evolution of the ammonia produced during the decomposition of the animal matters they contain. This escape of ammonia, even when imperceptible by the sense of smell, is easily detected by holding over the heap a feather dipped in vinegar or in spirit of salt (muriatic acid), when white fumes are immediately perceived if ammonia be present.

when wholesome, by the roots of plants; or to be carried off by the drains when injurious to vegetation.

4°. I have already alluded to the fact that this gas being absorbed by porous substances, and to its presence, in consequence, in porous soils, and in burned bricks and clay. With the purer kinds of unburned clay, however, and with the oxide of iron contained in red (or ferruginous)* soils, ammonia is supposed to form a chemical compound of a weak nature. In consequence of its affinity or feeble tendency to combine with these substances, they attract it from the air, and from decaying animal or vegetable matters, and retain it more strongly than many porous substances can,—yet with a sufficiently feeble hold to yield it up, readily as is supposed, to the roots of plants, when their extremities are pushed forth in search of food. In this case the carbonic, acetic and other acids given off, or supposed to be given off by the roots, exercise an influence to which more particular allusion will be made hereafter.

6°. In the state of carbonic it decomposes gypsum forming carbonate of lime (chalk) and sulphate of ammonia.† The action of gypsum on grass lands, so undoubtedly beneficial in many parts of the world, has been ascribed to this *single* property; it being supposed that the sulphate of ammonia formed, is peculiarly favourable to vegetation. This question will come properly under review hereafter. I may here, however, remark that if this be the *sole* reason for the efficiency of gypsum, its application ought to be beneficial on all lands not already abounding either in gypsum or in sulphate of ammonia ‡ But if the results of experimental farming in this country are to be trusted, this is by no means the case. The action neither of this, nor probably of any other inorganic substance applied to the soil, is to be explained by a reference in *every* case to one and the *same* property only.

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* Soils reddened by the presence of oxide of iron.

† Gypsum is *sulphate* of lime—consisting of sulphuric acid (oil of vitriol) and quicklime. Carbonate of ammonia consists of carbonic acid and ammonia. When the two substances act upon each other in a moist state—the two acids change places—the sulphuric acid as it were *preferring* the ammonia, the carbonic acid the lime.

‡ Liebig says—"the striking fertility of a meadow on which gypsum is strewed depends *only* on its fixing in the soil the ammonia of the

7°. The presence or evolution of ammonia in a soil containing animal and vegetable matter in a decaying state, induces or disposes this matter to attract oxygen from the

atmosphere, which would otherwise be volatilized with the water which evaporates."*—*Organic Chemistry applied to Agriculture*, p. 86.

When we come to consider the subject of mineral manures in general, we shall study more in detail the specific action of gypsum in promoting vegetation—a very simple calculation, however, will serve to show that the above theory of Liebig is far from affording a satisfactory explanation of all the phenomena.

Supposing the gypsum to meet with a sufficient supply of ammonia in the soil, and that it exercises its full influence, 100 lbs. of common *unburned* gypsum will fix or form sulphate with nearly 20 lbs. of ammonia containing 16½ lbs. of nitrogen. One hundred weight, therefore, (112 lbs.) will form as much sulphate as will contain 22½ lbs. of ammonia, and if introduced without loss into the interior of plants will furnish them with 18½ lbs. of nitrogen.

1°. In the first volume of British Husbandry, pp. 322, 323, the following experiment is recorded:

Mr. Smith, of Tunstal, near Sittingbourne, top-dressed one portion of a field of red clover with powdered gypsum at the rate of five bushels (or four hundred weight†) per acre, and compared the produce with another portion of the same field, to which no manure had been applied. The first crop was cut for hay, and the second ripened for seed. The following were the comparative results per acre:

	HAY CROP.	SEED.		STRAW.		
	cwt.	*qrs.*	*lbs.*	*cwt.*	*qrs.*	*lbs.*
Gypsumed	60	3	21	22	3	12
Unmanured	20	0	20	5	0	0
Excess of produce .	40	3	1	17	3	12

The excess of produce in all the three crops upon the gypsumed land is very large: let us calculate how much nitrogen this excess would contain. In a previous lecture (II. p. 33) it was stated as the result of Boussingault's analyses, that dry clover-seed contained 7 per cent of

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[* By *fixing* is meant the forming of *sulphate* with the ammonia. Rain water is supposed to bring down with it *carbonate of ammonia* (common smelling salts), which acts upon the *sulphate of lime* (gypsum) in such a way that *sulphate of ammonia* and *carbonate of lime* are produced. The carbonate of ammonia readily volatilizes or rises again into the air, the sulphate does not—hence the use of the word *fix*.]

[† A ton of pure gypsum, when crushed, will yield 25 bushels. It should, however, always be applied by *weight*.]

air more rapidly and abundantly. The result of this is, that organic acid compounds are formed, which combine with

nitrogen, and the same experimenter found in the hay of *red clover* 1½ per cent.* (or 70 and 15 lbs. respectively in 1000.)

The seed as it was weighed by Mr. Smith would still contain one-ninth of its weight of water,† and, consequently, only 6 1-3rd per cent. of nitrogen. Let it be taken at 6 per cent. and let the *straw* be supposed to contain only 1 per cent. of nitrogen, the quantity of this element being found to diminish in the grasses after the seed has ripened, and averaging 1 per cent. in the straw of wheat, oats, and barley, the weight of nitrogen reaped in the whole crop will then be as follows:

1. 40 cwt. of hay (4480 lbs.) at 1½ per cent. of nitrogen, contain 67 lbs.
2. 85 lbs. of seed at 6 per cent. contain . . . . 5 lbs.
3. 17 cwt. 3 qrs. 12 lbs. or 2000 lbs. of straw at 1 per cent. contain 20 lbs.

Total nitrogen in the excess of crop, 92 lbs.

But as above shown, the five bushels or four cwt. of gypsum could fix only 90 lbs. of ammonia containing 74 lbs. of nitrogen, *leaving, therefore,* 18 *lbs. or one-fifth part of the whole, to be derived from some other source.*

Now this result supposes that none of the gypsum or sulphate of ammonia was carried away by the rains, but that the whole remained in the soil, and produced its greatest possible effect on the clover—*and all in one season.*

But the effect of the gypsum does not disappear with the crop to which it is actually applied. Its beneficial action is extended to the succeeding crop of wheat, and on grass lands the amelioration is visible for a succession of years. If, then, the increased produce of a single year may contain more nitrogen than the gypsum can be supposed to yield, this substance must exercise some other influence over vegetation than is involved in its supposed action on the indefinite quantity of ammonia in the atmosphere.

2°. Again, Mr. Barnard, of Little Bordean, Hants, applied 2½ cwt. per acre on two-year old sain-foin, on a clayey soil. The increased produce of the first cutting was a ton per acre, and in October fully a ton, the undressed part yielding scarcely any hay at all, while the dressed part gave 1½ tons. The second year no gypsum was applied, and the difference is said to have been at least as great.

Supposing the increased produce in all to have been 4 tons of hay, and the nitrogen it contained to have been only one per cent—the 4 tons (8960 lbs.) would contain about 90 lbs. of nitrogen. But 2½ cwt. would fix only 46 lbs. of nitrogen in the form of ammonia; and therefore, supposing it to have produced its maximum effect, *there remain* 44 *lbs. or nearly one half of the whole, unaccounted for by the theory.*

I would not be understood to place absolute reliance on the results of the above experiments; but the way in which such results may be easily

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[* Ann. de Chim. et de Phys. lxiii. p. 225.]

[† See Lecture II. p. 33.]

the ammonia, and form ammoniacal salts.* On the decomposition of these salts by lime or otherwise—the organic acids which are separated from them, are always more advanced towards that state in which they again become fit to act as food for plants.

8°. But the most interesting, and perhaps the most important property of ammonia, is one which I have already had occasion to bring under your notice, as possessed by water also, and as peculiarly fitting that fluid for the varied functions it performs in reference to vegetable life. This property is the ease with which it undergoes decomposition, either in the air, in the soil, or in the interior of plants.

In the air it is diffused through, and intimately mixed with, a large excess of oxygen gas. In the soil, especially near the surface, it is also continually in contact with oxygen. By the influence of electricity in the air, and of lime and other bases in the soil, it undergoes a constant though gradual decomposition (oxidation), its hydrogen being chiefly converted into water, and a portion of its nitrogen into nitric acid.†

In the interior of plants this and other numerous and varied decompositions in all probability take place.

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applied for the purpose of testing theoretical views, will, I hope, convince the intelligent practical agriculturist how important it is, that the results of some of the experiments he is every year making should be accurately determined by *weight and measure*. By this means data would gradually be accumulated, on which we might hope to found more unexceptionable explanations of the phenomena of vegetation, than the results obtained in our laboratories have hitherto enabled us to advance.

In a subsequent note it will be shown that the mode in which the nitrates of soda and potash act—in other words, the theory of their action upon vegetation—may be tested by a similar simple calculation, and the importance of precise experiments made on the farm will then still further appear. It is in the hope of inducing some of my readers to make comparative trials and publish *accurate* results, that I have introduced into the Appendix (No. I.) an outline of the mode in which such experiments may most usefully be performed.

* Organic *acids* generally contain more oxygen in proportion to their carbon and hydrogen, than those which are *alkaline* or *neutral*.

† It will be remembered that ammonia is represented by NH^3, water by HO, and nitric acid by $N\,O^5$. It is easy to see, therefore, how, by means of oxygen, ammonia should be converted into water and nitric acid.

The important influence which ammonia appears to exercise over the growth of plants—the evidence for which I shall presently lay before you—is only to be explained on the supposition that numerous transformations of organic substances are effected in the interior of living vegetables—which transformations all imply the separation from each other, or the *re*-arrangement of the elements of which ammonia consists. In the interior of the plant we have seen that water, ever present in great abundance, is also ever ready to yield its hydrogen or its oxygen as occasion may require, while these same elements are never unwilling to unite again for the formation of water. So it is, to a certain degree, with ammonia. The hydrogen it contains in so large a quantity is ready to separate itself from the nitrogen in the interior of the plant, and, in concert with the other organic elements introduced by the roots or the leaves, to aid in producing the different solid bodies of which the several parts of plants are made up. The nitrogen also becomes fixed in the coloured petals of the flowers, in the seeds, and in other parts, of which it appears to constitute a necessary ingredient—passes off in the form of new compounds, in the insensible perspiration or odoriferous exhalations of the plant,—or returning with the downward circulation, is thrown off by the root into the soil from which it was originally derived. Much obscurity still rests on the actual transformations which take place in the interior of plants, yet we shall be able in a future lecture, I hope, to arrive at a tolerably clear understanding of the general nature of many of them.

Such are the more important of those properties of ammonia, to which we shall hereafter have occasion to advert. The sources, remote as well as immediate, from which plants derive this, and the other compounds we have described as contributing to the nourishment and growth of plants, will be detailed in a subsequent section.

§ 6. *Nitric acid, its constitution and properties.*

When the nitre or saltpetre of commerce is introduced into a retort, covered with strong sulphuric acid (oil of vitriol*) and heated over a lamp or a charcoal fire, red fumes are given off, and a transparent, often brownish or reddish liquid, distils over, which may be collected in a bottle or other receiver of glass. This liquid is exceedingly acid and corrosive. In small quantity it stains the skin and imparts a yellow colour to animal and vegetable substances. In larger quantity it corrodes the skin, producing a painful sore, rapidly destroys animal and vegetable life, and speedily decomposes and oxidizes† all organic substances. Being obtained from nitre, this liquid is called nitric acid. It consists of nitrogen combined with oxygen, one equivalent of the former (N) being united to 5 of the latter (O^5), and is represented by NO^5.

This acid contains much oxygen, as its formula indicates, and its action on nearly all organic substances depends upon the ease with which it is decomposed, and may be made to part with a portion of this oxygen.

In nature, it never occurs in a free state; but it is found in many intertropical (hot) countries in combination with potash, soda, and lime—in the state of *nitrates*. It is an important character of these nitrates that, like the salts of ammonia they are all very soluble in water. Those of soda, lime, and magnesia attract moisture from the air, and in a damp atmosphere gradually assume the liquid form.

Saltpetre is a compound of nitric acid with potash (nitrate of potash). It is met with in the surface soil of many districts in Upper India, and is separated by washing the soil and subsequently evaporating (or boiling down) the clear liquid thus obtained. When pure it does not become moist on exposure to the air. It is chiefly used in the manufacture of gunpowder, but has also been recommended and frequently and successfully tried by the practical husbandman, as an influential agent in promoting vegetation.

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* Sulphuric acid is a compound of oxygen and sulphur, which is prepared by burning sulphur with certain precautions in large leaden chambers. It is also obtained directly by distilling *green vitriol* (sulphate of iron) at a high temperature in an iron still—hence its name *oil of vitriol.* It is a heavy, oily, acid, and remarkably corrosive liquid. In a concentrated state, it is exceedingly destructive both to animal and to vegetable life.

† When a substance combines with *oxygen*, either in consequence of exposure to the air or in any other circumstances, it is said to become *oxidized.*

In combination with soda, it is found in deposits of considerable thickness in the district of Arica in Northern Peru, from whence it is imported into this country, chiefly for the manufacture of nitric and sulphuric acids. More recently its lower price has caused it to be extensively employed in husbandry, especially as a top-dressing for grass lands. Like the acid itself, these nitrates of potash and soda, when present in large quantities, are injurious to vegetation. This is probably one cause of the barrenness of the district of Arica in Peru, and of other countries, where in consequence of the little rain that falls, the nitrous incrustations are accumlated upon the soil. In small quantity they appear to exercise an important and salutary influence on the rapidity of growth, and on the amount of produce of many of the cultivated grasses. This salutary influence is to be ascribed, either in whole or in part, to the constitution and nature of the nitric acid, which these salts contain. It is chiefly with a view to the explanation I shall hereafter attempt to give of the nature of this salutary action, that I have thought it necessary here to make you acquainted with this *acid* compound of nitrogen and *oxygen*, in connection with the *alkaline* compound (ammonia) of the same gas with *hydrogen*.

Having thus shortly described both the organic elements themselves, and such chemical compounds of these elements as appear to be most concerned in promoting the growth of plants, we are prepared for entering upon the consideration of several very important questions. These questions are—

1°. From what source do plants derive the organic elements of which they are composed?

2°. In what form do plants take them up—or what proof have we that the compounds above described, really enter into plants?

3°. By what organs is the food introduced into the circulation of plants? In consequence of what peculiar structure of these several parts are plants enabled to take up the compounds by which they appear to be fed; and what are the functions of these parts, by the exercise of which the food is converted and appropriated to their own sustenance and further growth ?

4°. By what chemical changes is the food *assimilated* by plants, that is—after being introduced into the circulation, through what series of chemical changes does it pass, before it is converted by the plant into portions of its own substance ?

5°. By what natural laws or adaptations is the supply of those compounds, which are the food of plants, kept up ? Animals are supported by an unfailing succession of vegetable crops,—by the operation of what invariable laws is food continually provided for plants ?

These questions we shall consider in succession.

LECTURE IV.

Source of the organic elements of plants—Source of the carbon—Form in which it enters into the circulation of plants—Source of the hydrogen—Source of the oxygen—Source of the nitrogen—Form in which nitrogen enters into the circulation of plants—Absorption of ammonia and nitric acid by plants.

The first of the series of questions stated at the close of the preceding lecture, regards the source from which plants derive the organic elements of which they are composed. They are supported, it is obvious, at the conjoined expense of the earth and the air—how much do they owe to each, and for which elements are they chiefly and immediately indebted to the soil, and for which to the atmosphere? We must first consider the source of each element separately.

§ 1. *Source of the carbon of plants.*

We have already seen reason to believe that carbon is incapable of entering directly, in its solid state, into the circulation of plants. It is generally considered, indeed, that solid substances of every kind are unfit for being taken up by the organs of plants, and that only such as are in the liquid or gaseous state, can be absorbed by the minute vessels of which the cellular substances of the roots and leaves of plants are composed. Carbon, therefore, must enter either in the gaseous or liquid form, but from what *source* must it be derived? There are but two sources from which it can be obtained,—the soil in which the plant grows—and the air by which its stem and leaves are surrounded.

In the soil much vegetable matter is often present, and the farmer adds vegetable manure in large quantities with the view of providing food for his intended crop. Are plants really fed by the vegetable matter which exists in the soil or by the vegetable manure that is added to it?

This question has an important practical bearing. Let us, therefore, submit it to a thorough examination.

1°. We know, from sacred history, what reason and science concur in confirming, that there was a time when no vegetable matter existed in the soil which overspread the earth's surface. The first plants must have grown without the aid of either animal or vegetable matter—that is, they must have been nourished from the air.

2°. It is known that certain marly soils, raised from a great depth beneath the surface, and containing apparently no vegetable matter, will yet, without manure, yield luxuriant crops. The carbon in such cases must also have been derived from the air.

3°. You know that some plants grow and increase in size when suspended in the air, and without being in contact with the soil.

You know, also, that many plants—bulbous flower roots for example—will grow and flourish in pure water only, provided they are open to the access of the atmospheric air. Seeds also will germinate, and when daily watered, will rise into plants, though sown in substances that contain no trace of vegetable matter.

Thus De Saussure found that two beans, when caused to vegetate in the open air on pounded flints, doubled the weight of the carbon they originally contained.

Under similar circumstances Boussingault found the seeds of trefoil increase in weight 2½ times, and wheat gave plants equal in weight, when dry, to twice that of the original grains.* The source of the carbon in all these cases cannot be doubted.

4°. When lands are impoverished, you lay them down to grass, and the longer they lie undisturbed the richer in vegetable matter does the soil become. When broken up, you find a black fertile mould where little trace of organic matter had previously existed.

The same observation applies to lands long under wood. The vegetable matter increases, the soil improves, and when cleared and ploughed it yields abundant crops of corn.

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* Ann. de Chim. et de Phys. lxvii. p. 1.

Do grasses and trees derive their carbon from the soil? Then, how, by their growth, do they increase the quantity of carbonaceous matter which the soil contains? It is obvious that, taken as a whole, they must draw from the air not only as much as is contained in their own substance, but an excess also, which they impart to the soil.

5°. But on this point the rapid growth of peat may be considered as absolutely conclusive. A tree falls across a little running stream, dams up the water, and produces a marshy spot. Rushes and reeds spring up, mosses take root and grow. Year after year new shoots are sent forth and the old plants die. Vegetable matter accumulates; a bog, and finally a thick bed of peat is formed.

Nor does this peat form and accumulate at the expense of one species or genus of plants only. Latitude and local situation are the circumstances which chiefly affect this accumulation of vegetable matter on the soil. In our own country, the lowest layers of peat are formed of aquatic plants, the next of mosses, and the highest of heath. In Terra del Fuego, "nearly every patch of level ground is covered by two species of plants (*astelia pumila* of Brown, and *donatia magellanica*), which, by their joint decay, compose a thick bed of elastic peat." "In the Falkland Islands almost every kind of plant, even the coarse grass which covers the whole surface of the island, becomes converted into this substance."*

Whence have all these plants derived their carbon? The quantity originally contained in the soil is, after a lapse of years, increased ten thousand fold. Has dead matter the power of reproducing itself? You will answer at once, that all these plants must have grown at the expense of the air, must have lived on the carbon it was capable of affording them, and as they died must have left this carbon in a state unfit to nourish the succeeding races.

This reasoning appears unobjectional, and, from the entire group of facts, we seem justified in concluding that plants every where, and under all circumstances, derive the whole of their carbon from the atmosphere.

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* *Darwin's Researches in Geology and Natural History*, pp. 349-50. Dr. Greville informs me that the *astelia* approaches more nearly to the junceæ or *rush tribe*, and the *donatia* to our tufted saxifrages, than to any other British plants.

In certain extreme cases, as in those of plants growing in the air and in soils perfectly void of organic matter, this conclusion must be absolutely true. The phenomena admit of no other interpretation. But it is as strictly true of the more usual forms of vegetable life, or in the ordinary circumstances in which plants grow spontaneously or are cultivated by the art of man? Has the vegetable matter of the soil no connection with the growth of the trees or herbage?—does it yield them no regular supplies of nourishment? Does nature every where form a vegetable mould on which her wild flowers may blossom and her primeval forests raise their lofty heads? Has the agricultural experience of all ages and of all countries led the practical farmer to imitate nature in preparing such a soil? Does nature work in vain?—is all this experience to be at once rejected?

While we draw conclusions, legitimate in kind, we must be cautious how, in degree, we extend them beyond our premises.

The consideration of one or two facts will show that our general conclusion must either be modified or more cautiously expressed.

1°. It is true that plants will, in certain circumstances, grow in a soil containing no sensible quantity of organic matter—but it is also true, *generally*, that they do not luxuriate or readily ripen their seed in such a soil.

2°. It is consistent with almost universal observation, that the same soil is more productive when organic matter is present, than when it is wholly absent.

3°. That if the crop be carried off a field, less organic matter is left in the soil than it contained when the crop began to grow, and that by constant cropping the soil is gradually exhausted of organic matter.

Now it must be granted that tillage alone, without cropping, would gradually lessen the amount of organic matter in the soil, by continually exposing it to the air and hastening its decay and resolution into gaseous substances, which escape into the atmosphere. But two years open fallow, with constant stirring of the land, will not rob it of vegetable matter so effectually as a year of fallow succeeded by a crop of wheat. Some of the vegetable matter, therefore, which the soil contained when the seed was sown, must be carried off the field in the crop.

The conclusion therefore seems to be reasonable and legitimate, that the crop which we remove from a field has not derived all its carbon directly from the air—but has extracted a portion of it immediately from the soil. It is to supply this supposed loss, that the practical farmer finds it necessary to restore to the land in the form of manure—among other substances—the carbon also of which the straw or hay had robbed the soil.

But how is this reconcileable with our previous conclusion, that the whole of the carbon is derived from the air? The difficulty is of easy solution.

A seed germinates in a soil in which no vegetable matter exists; it sprouts vigorously, increases then slowly, grows languidly at the expense of the air, and the plant dies stunted or immature. But in dying it imparts vegetable matter to the soil, on which the next seed thrives better—drawing support not only from the air, but by its roots from the soil also. The death of this second plant enriches the soil further, and thus, while each succeeding plant is partly nourished by food from the earth, yet each, when it ceases to live, imparts to the soil all the carbon which during its life it has extracted from the air. Let the quantity which each plant thus returns to the soil, exceed what it has drawn from it by only one ten-thousandth of the whole, and —unless other causes intervene—the vegetable matter in the soil must increase.

Thus while it is strictly true that the carbon contained in all plants has *been originally* derived from the air, it is not true that the *whole* of what is contained in any one crop we raise, is *directly* derived from the atmosphere—the proportion it draws from the soil is dependent upon numerous and varied circumstances.

The history of vegetable growth, therefore—in so far at least as the increase of the carbon is concerned—may be thus simply stated:

1°. A plant grows partly at the expense of the soil, and partly at that of the air. When it reaches maturity, or when winter arrives, it dies. The dead vegetable matter decays, a part of it is resolved into gaseous matter and escapes into the air, a part remains and is incorporated with the soil. If that which remains be greater in quantity than that which the plant in growing derived from the soil, the vegetable matter will increase; if less, it will diminish.

2°. In warm climates the decay of dead vegetable matter is more rapid, and, therefore, the portion left in the soil will be less than in more temperate regions—in other words, the vegetable matter in the soil will increase less rapidly—it may not increase at all.

3°. As we advance into colder countries, the decay and disappearance of dead vegetable matter, in the form of gaseous substances which escape into the atmosphere, become more slow—till at length, between the parallels of 40° and 45°, it begins to accumulate in vast quantities in favourable situations, forming peat bogs of greater or less extent. While the living plant here, as in warm climates, derives carbon both from the earth and from the air, the dead plant, during its slow and partial decay, restores little to the atmosphere, and therefore adds rapidly to the vegetable matter of the soil.

4°. Again, in one and the same climate, the decay of vegetable matter, and its conversion into gaseous substances, is more rapid in proportion to the frequency with which it is disturbed or exposed to the action of the sun and air. Hence this decay may be comparatively slow in shady woods and in fields covered by thick sward of grass; and in such situations organic matter may accumulate, while it rapidly diminishes in an uncovered soil, or in fields repeatedly ploughed and subjected to frequent cropping.*

Being thus fitted, by nature, to draw their sustenance—now from the earth, now from the air, and now from both, according as they can most readily obtain it—plants are capable of living,—though rarely a robust life,—at the expense of either. The proportion of their food which they actually derive from each source, will depend upon many circumstances—on the nature of the plant itself—on the period of its growth—on the soil in which it is planted—on the abundance of food presented to either extremity—on the warmth and moisture of the climate—on the duration and intensity of the sunshine, and other circumstances of a similar kind—so that the only general law seems to be, that, like animals, plants have also the power of adapting themselves, to a certain extent, to the conditions in which they are placed; and of supporting life by the aid of such sustenance as may be within their reach.

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* In removing a crop we take away both what the plants have received from the earth and what they have absorbed from the air—the materials, in short, intended by nature to restore the loss of vegetable matter arising from the natural decay.

Such a view of the course of nature in the vegetable kingdom, is consistent, I believe, with all known facts. And that the Deity has bountifully fitted the various orders of plants—with which the surface of the earth is at once beautified and rendered capable of supporting animal life—to draw their nourishment, in some spots more from the air, in others more from the soil, is only in accordance with the numerous provisions we every where perceive, for the preservation and continuance of the present condition of things.

By taking a one-sided view of nature, we may arrive at startling conclusions—correct, if taken as partial truths, yet false, if advanced as general propositions—and fitted to lead into error, such as have not the requisite knowledge to enable them to judge for themselves—or such as, doubtful of their own judgment, are willing to yield assent to the authority of a name.

Of this kind appears, at first sight, to be the statement of Liebig, that "when a plant is quite matured, and when the organs by which it obtains food from the atmosphere are formed, the carbonic acid of the soil is no further required"—and that, "during the heat of summer it derives its carbon exclusively from the atmosphere."*

A little consideration will show us that, while the proposition contained in the former quotation may be entertained and advanced as a *matter of opinion*—the latter is obviously incorrect. In summer, when the sun shines the brightest, and for the greatest number of hours, the evaporation from the leaves of all plants (their insensible perspiration) is the greatest*—the largest supply of water, therefore, must at this season be absorbed by the roots, and transmitted upwards to the leaves. But this water, before it enters the roots, has derived carbonic acid and other soluble sebstances from the air and from the soil, in as large quantity at this period, as at any other during the growh of the plant; and these substances it will carry with it in its progress through the roots and the stem.

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* Organic Chemistry applied to Agriculture, p. 48.

Are the functions of the root changed at this stage of the plant's growth? Do they now absorb pure water only, carefully separating and refusing to admit,—even such substances as are held in *solution*? Or do the same materials which minister to the growth of the plant in its earlier stages, now pass upwards to the leaf and return again in the course of the circulation unchanged and unemployed, to be again rejected at the roots? Does all this take place in the height of summer, while the plant is still rapidly increasing in size? The opinion is neither supported by facts nor consistent with analogy.

But such an opinion,—however the words above quoted may mislead some,—it is not intended to be advanced by Liebig; for, in the following page he says, that "the power which roots possess of taking up nourishment does not cease so long as nutriment is present." In summer, therefore, as well as in spring or in autumn, the plant must be ever absorbing nourishment by these roots, if the soil is capable of affording it—and thus, in the general vegetation of the globe, the increase of carbon in growing plants must, at every season of the year, be partly derived from the vegetable matter of the soil in which they grow.

§ 2. *Form in which Carbon enters into the circulation of Plants.*

Supposing it to be established that the whole of the carbon contained in plants has originally been derived from the air—we have only to inquire in what state this element exists in the atmosphere, in order to satisfy ourselves as to the *form* of combination in which it is and has been received, into the circulation of plants. In considering the constitution of the atmosphere in the preceding lecture, it was stated that carbonic acid, a compound of carbon and oxygen, is always present in it—and that, though this gas is diffused through the air in comparatively small quantity only, yet it is every where to be detected,—while no other compound of carbon is to be found in it in any appreciable quantity. We must conclude, therefore, that from this gaseous carbonic acid the whole of the carbon contained in plants has been *primarily* derived. This conclusion is confirmed by the observation so frequently made, that the leaves of plants in sunshine absorb carbonic acid, and that plants die in an atmosphere from which this gas is entirely excluded.

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* Lindley's Theory of Horticulture, p. 46.

But we have seen reason to believe that, under existing circumstances, plants also extract a portion of the carbon they contain from the soil in which they grow. In what state or form of combination do the *roots* absorb carbon?

The most abundant product of the decay of vegetable matter in the soil, is the same carbonic acid which plants inhale so largely from the atmosphere by their leaves. In a soil replete with vegetable matter, therefore, the roots are surrounded by an atmosphere more or less charged with carbonic acid. Hence if they are capable of inhaling gaseous substances, this gas will enter the roots in the aeriform state—if not, it must enter in solution in the water, which the roots drink in so largely, to supply the constant waste caused by the insensible perspiration of the leaves.

During the early fermentation of artificial manures there is also developed in the soil a variable proportion of light carburetted hydrogen (Lecture III., p. 64), which is supposed by some to enter occasionally into the roots. That it does enter, however, is doubtful,—and we are safe, I think, in considering this compound not only as an uncertain source of the carbon of plants, but as one from which, in the most favourable circumstances, they can derive only a small supply.

Thus, from the earth as from the air, the most unfailing supply of food is the gaseous carbonic acid.

But as the water passes through the soil it takes up inorganic substances—potash, soda, lime, magnesia—and conveys them through the roots into the circulation of the plants. Can it refuse to take up and to perform a similar office to the soluble organic substances it meets with, as it sinks through the soil? Or do the spongioles of the roots keep a perpetual watch over the entering waters, to prevent the introduction of every soluble form of carbon but that of carbonic acid? Or, supposing such substances introduced into the interior of the plant, are none of them *digested* there and converted to the general purposes of food? A statement of two or three facts will afford a satisfactory reply to these several questions.

1°. When plants are made to grow in infusions of madder the radicle fibres are tinged of a red colour.

2°. The flower of a white hyacinth becomes red after a few hours, when the earth in which it is planted is sprinkled with the juice of the *phytelaea decandra* (Biot.)

Therefore organic substances can enter into the roots, and thence into the circulation of the plant.

3°. The colour of the madder does not usually extend upwards to the leaves and flowers of the plant.

4°. The colour imparted to the flower of the white hyacinth disappears in the sunshine in the course of a few days.

Organic colouring matters, therefore, undergo a chemical change either in the stem, in the leaf, or in the flower—some sooner, some later—and the same is probably the case with most other organic substances which gain admission into the interior of plants.

5°. Sir Humphry Davy introduced plants of mint into weak solutions of sugar, gum jelly, the tanning principle, &c., and found that they grew vigorously in all of them. He then watered separate spots of grass with the same several solutions, and with common water, and found all to thrive more than that to which common water was applied

—while those treated with sugar, gum, and gelatine, grew luxuriantly.*

Therefore different organic substances—being introduced into the circulation and there changed—are converted by plants into their own substance, or *act as food, and nourish the plant.*

We may consider it therefore, to be satisfactorily established that, while a plant sucks in by its leaves and roots much carbon in the form of carbonic acid, it derives a *variable* portion of its immediate sustenance (of its carbon) from the soluble organic substances that are within reach of its roots.

This fact is never doubted by the practical husbandman. It forms the basis of many of his daily and most important operations, while the results of these operations are further proofs of the fact.

The nature of the soluble substances which are formed during the decay of animal and vegetable substances—and which the roots of plants are supposed to take up—will be considered in a subsequent lecture.†

§ 3. *Source of the hydrogen of plants.*

The source of the hydrogen of plants is less doubtful, and will require less illustration, than the source of the carbon. This elementary substance is not known to exist in nature in an uncombined state, and, therefore it must, like carbon, enter into plants in union with some other element.

1°. Water has been already shown to consist of hydrogen in combination with oxygen. In the form of vapour, this compound pervades the atmosphere, and plays among the leaves of plants while in the liquid state it is diffused through the soil, and is unceasingly drunk in by the roots of all living vegetables. In the interior of plants—at least during their growth—this water is continually undergoing decomposition and it is unquestionably the chief source of the hydrogen which enters into the constitution of their several parts. In explaining the properties of water I have already dwelt upon the apparent facility with which its elements are capable either of separating from, or of *re*-uniting to, each other, in the vascular system of animals or of plants. The reason and precise results of these transformations we shall hereafter consider.

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* Agricultural Chemistry, Lecture VI.

† This part of the subject might have been discussed here without appearing out of place—but it will come in more appropriately, I think, when treating of the nature and mode of action of *vegetable manures.*

2°. In light carburetted hydrogen (CH^2), given off as already stated during the decay of vegetable matter, and said to be always present in highly manured soils, this element, hydrogen, exists to the amount of nearly one-fourth of its weight. On the extent, therefore, to which this gaseous compound gains admission into the roots of plants, will depend the supply of hydrogen which they are capable of drawing from this source. Had we satisfactory evidence of the actual absorption of this (marsh) gas by the roots or *leaves* of plants, in any quantity, we should have no difficulty in admitting that plants might, from this source, easily obtain a considerable supply both of carbon and of hydrogen. It would be also easy to explain how (that is by what chemical changes), it is capable of being so appropriated. But the extent to which it really acts as food to living vegetables is entirely unknown.

3°. Ammonia is another compound, containing much hydrogen,* which, as I have already stated, exercises a manifest influence on the growth of plants. If this substance enter into their circulation in any sensible quantity,—if, as some maintain, it be not only universally diffused throughout nature, but is constantly affecting, and influencing at all times, the universal functions of vegetation—there can be no doubt that the hydrogen it contains must, to an equal extent, be concerned in the production of the various organic substances which are formed or elaborated by the agency of vegetable life. How far this probable interference of the hydrogen of ammonia with the functions of the vegetable organs, will tend to explain or illustrate the influence actually exerted by this compound, we shall, by and bye, more accurately inquire. In the mean time, the quantity of ammonia, which actually enters into the circulation of plants in a state of nature, is too little known, and making the largest allowance, probably too minute, to permit us to consider it as an important source of hydrogen to the general vegetation of the globe.

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* Its formula being NH^3, or one equivalent of nitrogen and three of hydrogen.

4°. The soluble organic substances, which enter into the circulation of plants through the roots, as shown in the preceding section, do not consist of carbon and water only, but of combinations of carbon with hydrogen and oxygen in various proportions. From these substances, therefore, plants derive an uncertain and indefinite supply of hydrogen in a state already half-organized, and probably, still more easily assimilated or converted into portions of their own substance, than when this element is combined with oxygen in the form of water.

We may, therefore, conclude generally in regard to the source of the hydrogen of plants—that though there are undoubtedly several other forms of combination in which this element may enter into their circulation, in uncertain quantity—yet that all-pervading water is the main and constant source from which the hydrogen of vegetable substances is derived.

§ 4. *Source of the oxygen of plants.*

We can at once perceive, and without difficulty, the various sources of the oxygen of plants; though it is difficult in this case also to say how much they derive from each.

1°. The water which they imbibe so largely consists in great part of oxygen,* and is easily decomposed. This alone would yield an inexhaustible supply.

2°. The atmosphere contains 21 per cent. of its bulk of oxygen, and the leaves of plants in certain circumstances are known to absorb this oxygen. The air in which they live, therefore, might be another source.

3°. Carbonic acid contains 72 per cent. by weight of oxygen, and this gas is also known to be absorbed in large quantity from the atmosphere by the leaves of plants—while its solution in water is admitted readily by the roots.

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* Eight-ninths of the weight of water are oxygen.

From any one of these sources an ample supply of oxygen might readily be obtained, and it may be considered as a proof of the vast importance of this element to the maintenance of animal and vegetable life, that it is every where placed so abundantly within the reach of living beings. It is from the first of these sources, however, from the water they contain, that plants are believed to derive their principal supply. The reasons on which this opinion is founded will appear, when we shall have considered the functions of the several parts of plants, and the chemical changes to which the food is subjected in the course of the vegetable circulation.

§ 5. *Source of the nitrogen of plants.*

The quantity of nitrogen present in plants is very small, compared with that of any of the other elements which enter into their constitution. Of this you will be reminded, by a reference to the analyses of hay, oats, and potatoes, exhibited in the second lecture (page 33), which show that the nitrogen contained in these several crops, when perfectly dried at 240° F., is respectively $1\frac{1}{3}$, $2\frac{1}{3}$, and $1\frac{1}{3}$ per cent. In the state in which they are usually given to cattle they contain a still less per centage of nitrogen, in consequence of the quantity of water still present in them. Thus raw potatoes as they are given to cattle contain only $\frac{1}{3}$ of a per cent. of nitrogen, hay $1\frac{1}{3}$ per cent., and oats $1\frac{9}{10}$* per cent. or a hundred pounds of each contain 5 ounces, 1 pound 5 ounces, and 1 pound 14 ounces respectively.

It would appear at first sight as if this small quantity of nitrogen could be of little importance to the plant, especially since, as we shall hereafter see, it does not enter as a constituent into those vegetable substances, such as woody fibre, starch, sugar, and gum, which plants produce in the greatest abundance, and of which their own stems and branches chiefly consist. The same remark, however, applies to this, as to many other cases which present themselves to the chemist, during his analyses, especially of organized substances,—that those elements which are present only in small quantity are as necessary—as essential—to the constitution of the particular substance in which they occur, as other elements are of which they contain much; and that if these small quantities are removed or absent, not only are the physical and chemical properties of the substance materially altered, but it is found also to exercise a very different influence on animal and vegetable life. This latter observation will present itself to you in a very striking light, when we come hereafter to study the nutritive properties of the several kinds of food by which animals are chiefly supported,—and shall see on what elementary body their relative nutritive properties depend, or by the amount of which their relative value appears at least to be indicated.

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* 0·33, 1·29, and 1·87 per cent—the potatoes containing also 72 per cent of water, the hay 14, and the oats 15 per cent.

But a consideration of the absolute quantity of nitrogen contained in an entire crop will satisfy you that though small in comparative amount,[*] this element cannot be without its due share of importance in reference to vegetable life. Hay, as above stated, contains, as it is stacked, 1⅓[†] per cent. of nitrogen, or a ton of hay contains 30 lbs. of this element. A good crop of hay, on land which is depastured during the winter, will amount to 2 or 2½ tons[‡] per acre. Taking 2 tons as an average, the hay from one acre will contain 60 lbs. of nitrogen, or from 100 acres 6000 lbs., equal to 2⅔ tons of nitrogen.

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[*] That is, compared with the carbon and oxygen which plants contain.

[†] In different crops of hay *Boussingault* found in three several years the following proportions of nitrogen:—

	Hay, as commonly stacked.	Hay dried at 230° F.	
In 1836	1·18	1·04	of nitrogen per cent.
" 1838	1·3	1·15	" "
" 1839	1·5	1·3	" "
" Aftermath	2·4	2·0	" "

[‡] The Rev. Mr. Ogle, of Kirkley, Northumberland, informs me that some of his land near the Hall has yielded annually at this rate for 100 years, and without other manure than the droppings from the cattle which have fed upon it.

Allowing, therefore, nothing for the aftermath, and supposing the other crops to contain no more nitrogen than the hay does, the farmer of five hundred acres will annually carry into his stack-yard at least 13 tons of nitrogen in the form of hay, straw, grain, and other produce.*

Nature performs all her operations on a large scale, and the quantity of materials she employs are large in a corresponding degree. Hence, though *comparatively* small, the nitrogen in vegetable substances is *absolutely* large. You cannot suppose, when viewed in this light, that nitrogen is an element of little consequence in reference to vegetable life; or that in nature it should be so constantly and universally diffused without reference to some important end. If I may be allowed a familiar illustration of the mode in which small quantities of matter will affect the sensible properties of large masses, I would recall to your minds the effects of seasoning upon food, in imparting, when added in small quantity only, an agreeable relish to what would otherwise be insipid. But I need not dwell on this point, since I shall hereafter have occasion to draw your attention to certain facts in reference to the constitution of the atmosphere, which will satisfy you that, by the agency of *comparatively* feeble causes, gigantic effects are continually produced in nature,—and that we can scarcely fall into a graver error in reasoning of natural processes, than by overlooking the agency of forms of matter which present themselves to our senses in minute quantity only. In reference to insect life this truth has been long established. In the coral reefs you are familiar with the wonderful results of the preserving labour of minute animals in one element. When I come to explain the nature and origin of soils, I shall have occasion to show that even the element on which you labour—the earth, on the cultivation of which your thoughts and hands are daily employed—is occasionally indebted for some of its most valuable properties to a similar agency, often unseen by you, and though working for your good, unheeded and unthought of.

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* This *average* estimate gives but an inaccurate idea of the quantity actually contained in some species of crops. Thus red clover with the aid of gypsum will yield 3 tons of hay per acre. This hay contains more than twice the quantity of nitrogen (Boussingault) that common hay does, hence an acre of such hay would contain at least 180 lbs. of nitrogen. (See Lecture II., p. 33.)

Whence, then, is this nitrogen derived by plants? The *primary* source it is not difficult to see. We can arrive at it by a train of reasoning similar to that which led us to the atmosphere as the original source of the carbon of plants. Nitrogen does not constitute an *ingredient* of any of the solid rocks,* nor do we know any other source than the atmosphere from which it can be obtained in very large quantity. It exists, as we have seen, in many vegetables, and it is more largely present in animal substances, but these organized matters must themselves have drawn this element from a foreign source, and the atmosphere is the only one from which we can fairly assume it to have been originally derived.

But though the nitrogen, like the carbon of plants, may thus be traced to the atmosphere—as its original source—it does not follow that this element is either absorbed *directly* from the air, or, in an uncombined and gaseous state. Though the leaves of trees and herbs are continually surrounded by nitrogen, the constitution of plants may be unfitted for absorbing it by their leaves. The nitrogen may not only require to be in a state of combination before it can enter into the circulation, but it may also be capable of gaining admission only by the roots. These points are considered in the following section.

§ 6. *Form in which the nitrogen enters into the circulation of Plants.*

The question as to the form in which nitrogen enters into the circulation of plants is one which at the present moment engages much attention. It will be proper, therefore, to discuss it with considerable care.

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* Except coal, and coal itself is of vegetable origin. Throughout all rocks in which organic remains are found, more or less animal matter containing nitrogen is to be met with, but these remains are only accidentally present, and they must have derived their nitrogen during life, either directly or indirectly, from the atmosphere.

1°. It is considered an essential part of good tillage to break up and loosen the soil, in order that the air may have access to the dead vegetable matter, as well as to the living roots which descend to considerable depths beneath the surface. When thus admitted to the roots, it is impossible that some of the nitrogen of the atmosphere, as well as some of its oxygen, may be directly absorbed and appropriated by the plant. To what extent this absorption of nitrogen may proceed, however, we have as yet no experimental results from which we can form any estimate. Whether it takes place at all or not, is wholly a matter of opinion.

2°. The leaves of plants, as will be more fully explained hereafter, absorb certain gaseous substances from the atmosphere, and we might, therefore, expect that some of the nitrogen of the air would, by this channel, be admitted into their circulation. This view, however, is not confirmed by any of the experiments hitherto made with the view of investigating the action and functions of the leaves.* We are not at liberty, therefore, to assume that any of the nitrogen which plants contain has in this way been derived directly from the air. It may be the case; but it is not yet proved.

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* See subsequent lecture "*On the structure and functions of the several parts of plants.*"

The experiments above referred to were made upon plants growing in close vessels, the air contained in which was measured and examined (analysed) both before the plants were introduced and afrer they had been some time in the vessel. In these experiments the bulk of the nitrogen present has sometimes been observed to increase, but *never to diminish*, in quantity. The conclusion seems satisfactory, that no nitrogen is abstracted directly from the atmosphere by the leaves of plants. Yet Boussingault† very justly remarks, that a diminution in the bulk of the nitrogen,

[† Boussingault details a series of experiments in the course of which he made peas, trefoil, wheat, and oats, grow in the same pure siliceous sand containing no organic matter, and watered them with the same distilled water. The absolute quantity of nitrogen increased sensibly in the peas and trefoil during their growth; in the wheat and oats no change could be detected by analysis. From these results he is inclined to infer that the green leaves of the former have the power of *sensibly* absorbing nitrogen from the atmosphere, while those of the latter have not this power—at least under the circumstances in which the experiments were made. This conclusion, however, is not *certain*, as will presently be shown.—See *Ann. de Chim. et de Phys.* lxvii. p. 1. and lxix., p. 353.]

3°. There is little doubt, however, that nitrogen enters the roots of plants in a state of solution. But the quantity they thus absorb is uncertain—it is supposed to be small, and must be variable.

When water is exposed to the air in an open vessel it gradually absorbs oxygen and nitrogen, though, as has been stated in a previous lecture, in proportions different from those in which they exist in the atmosphere. The whole quantity of the mixed gases thus taken up amounts to about 4 per cent. of the bulk of the water (Humboldt and Gay-Lussac), and in rain water about ⅔ of the whole consist of nitrogen. One hundred cubic inches of rain water, therefore, will carry into the soil about 2⅔ inches of nitrogen gas. But in passing through the soil, the water meets with other soluble substances before it reaches the roots, especially the deep-seated roots of plants. It takes up carbonic acid, and it dissolves solid substances, and in doing so it is a property of water to give off a portion of the other gases which it had previously absorbed from the air.

But let us suppose that rain water actually takes to the roots, and carries with it into the circulation of the plant, 2 per cent. of its bulk of nitrogen, and let us calculate how much of the nitrogen it contains a crop of hay could in this way derive from the air.

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too small to be detected in the ordinary mode of making these experiments, would be sufficient to account for a considerable portion of that comparatively small quantity of nitrogen which is present in all living plants. While, therefore, we accord their due weight to these researches of the vegetable physiologists, we are not to consider them as by any means decisive of the question. With this rational and cautious conclusion, Liebig is not satisfied; he says, "We have not the slightest reason for believing that the nitrogen of the atmosphere takes part in the processes of assimilation of plants and animals; on the contrary, we know that many plants emit the nitrogen which is absorbed by their roots either in the gaseous form or in solution in water." (p. 70.) But if they occasionally expire nitrogen by their leaves, why must this nitrogen be exactly that portion which has previously been absorbed by the roots in the uncombined state, and the quantity of which is so uncertain and so indifinite?

The quantity of rain that falls at York from the first of March to the middle of June—during which time the grass grows and generally ripens—is about five inches.* On a square foot, therefore, there fall 720 cubic inches of water, containing two per cent. of their bulk, or 14 cubic inches, of nitrogen, weighing 4¼ grains. This gives 28 lbs. for the quantity of nitrogen thus brought to the soil over an entire acre. But if we consider how the rain falls in our climate, we cannot suppose the grass in a field to absorb by its roots, and afterwards perspire by its leaves, more than one third of the whole. This quantity would carry with it 9 lbs. of nitrogen into the circulation of the plants—or little more than a seventh part of the 60 lbs. which, as we have seen, are taken off the field in a crop of hay.

Such a calculation as this affords at the best but a very rude approximation to the truth—it seems, however, to justify us in concluding that plants can derive from the air, and in an uncombined state, only a small portion of the nitrogen they are found to contain—and that they probably draw a larger supply from certain *compounds* of this elementary substance with hydrogen and oxygen—which are known to come within the reach of their roots and leaves.

The most important of these compounds, and those perhaps the most extensively concerned in influencing vegetation, are ammonia and nitric acid, the properties of which have been described in the preceding lecture.†

§ 7. *Absorption of Ammonia by plants.*

That ammonia enters directly into the circulation of plants is rendered probable by a variety of considerations.

1°. Thus it is found to be actually present in the juices of many plants. In that of the beet-root, and in those of the birch and maple trees, it is associated with cane sugar (Liebig.) In the leaves of the tobacco plant, and of scurvy grass, in elder flowers, and in many fungi,[*] it is in combination with acid substances, and may be detected by mixing their juices with quicklime.

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* The result of experiments made in 1834 by Prof. Phillips and Mr. Edward Gray. The mean annual fall of rain at York is about 22 inches.—See fifth Report of the British Association, p. 173.

† It will be recollected that ammonia consists of one equivalent of nitrogen (N) united to three of hydrogen (H^3), being represented by NH^3; and that nitric acid consists of one of nitrogen (N) and five of oxygen (O^5), its formula being NO^5.—See Lecture III., p. 39.

2°. Some plants actually perspire ammonia. Among these is the *Chenopodium Olidum* (stinking goosefoot), which is described by Sir William Hooker as "giving out a most detestable odour, compared to putrid salt fish." In the odoriferous matter given off ammonia is contained, and may be detected by putting a glass shade over the plant, and after a time introducing a feather moistened with vinegar or dilute muriatic acid.[†] It is also present in the odoriferous exhalations of many sweet smelling plants and flowers.[‡]

3°. Nearly all vegetable substances, when distilled with water, yield an appreciable quantity of ammonia. Thus the leaves of hyssop, and the flowers of the lime tree, yield distilled waters in which ammonia can be detected (Schübler), the seeds of plants thus distilled yield it in abundance (Gay Lussac), and traces of it may be found in most vegetable extracts (Liebig).

4°. Ammonia is also given off, among other products, when wood is distilled in iron retorts for the manufacture of pyroligneous acid, and by a similar treatment it may be obtained from many other vegetable substances.

The above facts, however, are not to be considered as *proofs* that ammonia enters directly into the circulation of plants either by their roots or by their leaves. That which is associated with sugar in the beet, may have been formed by the same converting power which, in the interior of the plant, has produced the sugar from carbonic acid and water. So, that exhaled by the leaves of the goosefoot, which grows in waste places, especially near the sea, may have been produced during the upward flow of the sap or during its passage over the leaf. And we *know* that the nitrogen does not exist in the state of ammonia in the seeds of plants, or in wood, or in coal—though, from all of them it may be obtained by the processes above described.

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[*] Schübler *Agricultur Chemie*, II., p. 56.
[†] Chevallier *Jour. de Pharm.* X., p. 100,
[‡] Schübler, I., p. 152.

The production of ammonia, by the agency of a high temperature, may be illustrated by a very familiar experiment often performed, though for a very different purpose. The juice and dried leaf of tobacco contain nitre (nitrate of potash) and a *little* ammonia. But when tobacco is burned, ammonia in sensible quantity is given off along with the smoke, chiefly in the state of carbonate of ammonia. This may be shown by bringing a lighted cigar near to reddened litmus paper, when the blue colour will be restored; or to a red rose, when the leaves will become green; or to a rod dipped in vinegar or in dilute muriatic acid, when a white cloud will appear.*

In this case a portion of the ammonia given off by the tobacco has most probably been formed during the combustion, at the expense of the nitrogen contained in the nitrate of potash which is present in the leaf.

5°. But there are other circumstances which are strongly in favour of the opinion, that ammonia not unfrequently does enter, as such, into the circulation of plants.

Thus it is proved, by long experience, that plants grow most rapidly and most luxuriantly when supplied with manure containing substances of animal origin. These substances are usually applied to the roots or leaves in a state of fermentation or decay, during which they always evolve ammonia. Putrid urine and night-soil are rich in ammonia, and they are among the most efficacious of manures. This ammonia is *supposed* to enter into the circulation of plants along with the water absorbed by their roots, and sometimes even by the pores of their leaves. We can scarcely be said to have as yet obtained decisive proof that it does so enter, but probabilities are strongly in favour of this supposition; and when we come hereafter to consider minutely the mode in which it is likely to act, when within the plant, we shall find the probabilities derived from practical experience to be strengthened by the deductions of theory.

But though the facts so long observed in reference to the action of animal manures upon vegetation justify us in believing that ammonia actually enters into the roots, and perhaps into the leaves, of plants—we ought not hastily to conclude that all the nitrogen which plants are capable of deriving from decaying animal matter *must* enter into their circulation in the form of ammonia. Other soluble compounds containing nitrogen are formed during the decay of animal substances—they actually exist largely in the liquid manures of the stable and fold-yard, and they can scarcely fail, when applied to the soil, to be to a certain extent absorbed by the roots of plants. This *urea* is a substance containing much nitrogen, which exists in the urine or excrements of most animals, and by its decomposition produces carbonate of ammonia. But being very soluble, this substance may enter directly into the roots, and may be there decomposed, and made to give up its nitrogen to the living plant. To other compound substances of animal origin the same observation may apply,*—so that while the fact, that animal manure in a state of fermentation is very beneficial to vegetation, may be considered as rendering it highly probable that the ammonia which such manure contains, enters directly and supplies much nitrogen to the growing plants, it must not be entirely left out of view that, in nature, a portion of the nitrogen, derived from animal substances, may be obtained immediately from other compounds in which ammonia does not exist.

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* Runge, *Einleitung in die technische Chemie*, p. 375.

To what *amount* ammonia actually enters into the circulation of plants, or how much of the nitrogen they contain it actually supplies, we have no means of ascertaining. Were it abundantly present in the soil, its great solubility would enable it to enter, with the water absorbed by the roots, in almost unlimited quantity. In a subsequent section we shall consider the conditions under which ammonia is produced in nature, the comparative abundance in which it exists on the earth's surface, and the extent of the influence it may be supposed to exercise on the general vegetation of the globe.

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* Thus it may be applied more strongly to the *hippuric acid*, which exists in the urine of the horse, and other herbivorous animals. This acid decomposes naturally into *benzoic acid* and ammonia. The sweet-scented vernal-grass (*Anthoxanthum Odoratum*) by which hay is perfumed, owes its agreeable odour to the presence of this *benzoic acid*. It may, therefore, be supposed that, where cattle and horses graze, the grasses actually absorb the *hippuric* acid contained in the urine, which reaches their roots, decompose it as it ascends with the sap, appropriate its nitrogen, and exhale the odoriferous benzoic acid.

§ 8. *Absorption of nitric acid by plants.*

1°. That ammonia is actually present in the juices of many living vegetables has been adduced, as a kind of presumptive evidence, that this compound is directly absorbed by plants. A similar presumption is offered in favour of the direct entrance of nitric acid, by its invariable presence in combination with potash, soda, lime, or magnesia, in the juices of certain common and well known plants. Thus it is said to be always contained in the juices of the tobacco plant, of the sunflower, of the goosefoot,* and of common borage. The nettle is also said to contain it, and it has been detected in the grain of barley.† It exists probably in the juices of many other plants in which it has not hitherto been sought for. Were we, therefore, entitled, from the mere presence of this acid in plants, to infer that it had really entered by their roots or leaves, we should have no hesitation in drawing our conclusion. But, like ammonia, it may have been formed in the interior of the living vegetable;‡ and hence the fact of its presence proves nothing in regard to the state in which the nitrogen it contains entered into the circulation of the plant.

2°. But nitric acid, like ammonia, exerts a powerful influence on the growing crop, whether of corn or of grass. Animal matters, as we have seen, give off ammonia during their decay, and manures are rich and efficacious in proportion to the quantity of animal manure they contain.

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* *Chenopodium*, probably in all the species of this genus.—See Liebig, p. 82.

† Grisenthwaite (*New Theory of Agriculture*, p. 105) says it is always present in barley in the form of nitrate of soda.—*See Appendix*.

‡ When the beet-root arrives at maturity, the *sugar* begins to diminish, and saltpetre or other nitrates to be *formed*, probably at the expense of the ammonia which the juice previously contained.—Decroizelles, *Jour. de Phar.*, X., p. 42.

The crop produced also is valuable and rich in nitrogen in like proportion. Therefore, as already stated, it is inferred that ammonia enters directly into the living plant, and supplies it with nitrogen.

The effect of nitric acid is similar in kind, and perhaps equal in degree. Applied to the young grass or sprouting shoots of grain, it hastens and increases their growth, it occasions a larger produce of grain, and this grain, as when ammonia is employed, is richer in *gluten*, and more nutritious in its quality.[*] An equal breadth of the same field yields a heavier produce, and that produce, weight for weight, contains more when saltpetre or nitrate of soda have been applied in certain quantities to the young plants which grow upon it. It is reasonable to conclude, therefore, that the acid of the nitrates, in some form or other, is capable of entering into the circulation of living plants—and so yielding to them, in whole or in part, the nitrogen they contain.

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[*] The analogous effects of ammoniacal manures and of the nitrates on the relative quantities of *gluten* and starch in grain, are shown by the following experiments:

Hermbstaedt sowed equal quantities of the same wheat, on equal plots of the same ground, and manured them with equal weights of different manures. Then from 100 parts of each sample of grain produced, he obtained starch and gluten in the following proportions:

	Gluten.	Starch.	Produce.
Without manure . . .	9·2	66·7	3 fold.
With vegetable manure (rotted potato haulm) . . .	9·6	65·94	5 "
With cow dung . . .	12·0	62·3	7 "
With pigeons' dung . .	12·2	63·2	9 "
With horse dung . . .	13·7	61.64	10 "
With goats' dung . . .	32·9	42·4	12 "
With sheep dung . . .	32·9	42·8	12 "
With dried night-soil . .	33·14	41·44	14 "
With dried ox-blood . .	32.24	41·3	14 "
With dried humane urine .	35.1	39·3	12 "†

The manures employed by Hermbstaedt are *supposed* during fermentation, to evolve more ammonia in the order in which they are here placed, beginning at the top of the list; while the amount and kind of the produce obtained by the use of each, afford the chief evidence in favour of the opinion that this ammonia actually enters into and yields nitrogen to the plant.

Mr. Hyett found in flour raised on two patches of the same land in

[† Schübler. *Grundsätze der Agricultur Chemie,* II. p. 170.]

But here, again, as in the case of ammonia, we are at fault in regard to the quantity of their nitrogen which plants in a state of nature actually derive from nitric acid or the nitrates. The compounds of this acid with potash, soda, lime, and magnesia, (the nitrates of these substances), are all very soluble in water. The quantity of this fluid, therefore, which enters by the roots of plants, *could* easily convey into their circulation far more of these nitrates than would be alone sufficient to supply the whole of the nitrogen they require—for the formation of all their parts and products. But so it might of ammonia or its salts, as has already been shown. I shall hereafter lay before you certain considerations which may probably lead us to approximate conclusions in regard to the relative influence exercised by these two compounds on the general vegetation of the globe.

Conclusions.—Respecting the form in which nitrogen enters into the circulation of plants, we have, therefore, I think, fairly arrived at these deductions:

1°. That the nitrogen of the atmosphere may, to a small extent, enter directly into the living vegetable either in the form of gas or in solution in water, but that supposing ni-

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Gloucestershire, the one dressed with nitrate of soda, the other undressed, the following proportions:

	Gluten.	Starch.
In the nitrated	23·25	49·5
In the unnitrated	19·	55·5

And Dr. Daubeny, in flour from wheat top-dressed with saltpetre, found—

In the nitrated	15 per cent. of gluten.
In the unnitrated	13 " " *

These differences are not so striking as in the case of ammonia, but they are precisely *the same in kind*, and lead to the same general conclusion in regard to the nature of the influence of the nitrates on vegetation. Accurate and repeated experiments on the precise effects of the nitrates are still much to be desired.

[* *Three Lectures on Agriculture*, p. 76.]

trogen to be in this way appropriated* by the plant, the quantity so taken up could form only a small quantity of that which vegetables actually contain.

2°. That ammonia is *capable* of entering into plants in very large quantity, and of yielding nitrogen to them, and that in European agriculture, which employs fermenting animal manure as an important means of promoting vegetable growth, it does appear to yield to cultivated plants a considerable portion of the nitrogen they contain.

3°. That nitric acid, in like manner, is *capable* of entering into and giving up its nitrogen to plants; and that where this acid is employed as an instrument of culture, the crops obtained owe part of their nitrogen to the quantity of this compound which has been applied to the growing plants. The same inference may fairly be drawn in regard to the effect of nitric acid—when in the form of nitrates, it exists or is produced naturally in the soil.

4°. That other compound bodies, such as are contained in urine, or are produced during the decay of animal matter, may also enter into the circulation of plants, and yield nitrogen to promote their growth.

On the whole, however, there seem strong reasons for believing that plants are mainly dependent on ammonia and nitric acid for the nitrogen they contain; and that they obtain it most readily, and with least *labour*, so to speak, from these compounds,—though nature has kindly fitted them for deriving a stinted supply from other sources, when these substances are not present in sufficient abundance.

How far each of these compounds is employed by nature, as an instrument in promoting the general vegetation of the globe, will be considered in a subsequent lecture.

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* Liebig and others say that plants are *incapable* of appropriating or assimilating the nitrogen which enters into the circulation in the simple state, (Liebig, p. 70). We shall consider this question hereafter.

LECTURE V.

How does the food enter into the circulation of plants—Structure of the several parts of plants—Functions of the root—Course of the sap—Cause of its ascent—Functions of the stem—of the leaves—and of the bark—Circumstances by which the exercise of these functions is modified.

Having now taken a general view of the source from which plants derive the elementary substances of which their solid parts consist, and of the states of combination in which these elements enter into the vegetable circulation,—the next step in our inquiry is—*how* are these substances admitted into the interior of living plants—and under what conditions or regulations? We are thus led to study the structure and functions of the several parts of plants, and the circumstances by which the exercise of these functions is observed to be modified.

§ 1. *General structure of plants, and of their several parts.*

Plants consist essentially of three parts—the roots, the stem, and the leaves. The former spread themselves in various directions through the soil, as the latter do through the air, and the stem is dependent for its food and increase on the rapidity with which the roots shoot out and extend, and on the number and luxuriance of the leaves.

We shall obtain a clearer idea of the relative structure of these several parts by first directing our attention to that of the stem.

The stem consists aprarently of four parts—the pith, the wood, the bark, and the medullary rays. The pith and the medullary rays, however, are similarly constituted, and are only prolongations of one and the same substance. The pith forms a solid cylinder of soft and spongy matter, which ascends through the central part of the stem, and varies in thickness with the species and with the age of the trunk or branch. The wood surrounds the pith in the form of a hollow cylinder, and is itself covered by another hollow cylinder of bark. In trees or branches of considerable age the wood consists of two parts, the oldest or *heart wood*, often of a brownish colour, and the newer external wood or *alburnum*, which is generally softer and less dense than the heart wood. The bark also is easily separated into two portions, the inner bark or *liber*, and the *epidermis* or outer covering of the tree. The pith and the bark are connected together by thin vertical columns or partitions, which intersect the wood and divide it into triangular segments. A cross section of the trunk or branch of a tree exhibits these thin columns extending in the form of rays, or like the spokes of a wheel, from the centre to the circumference. Though they form in reality thin and continuous vertical plates, yet from the appearance they present in the cross section of a piece of wood, they are distinguished by the name of medullary rays.

These several parts of the stem are composed of bundles of small tubes or hollow cylindrical vessels of various sizes, and of different kinds, the structure of which it is unnecessary for us to study. They are all intended to contain liquid and gaseous substances, and to convey them in a vertical, and sometimes in a horizontal, direction. The tubes which compose the wood and bark are arranged vertically, as may readily be seen on examining a piece of wood even with the naked eye, and are intended to convey the sap upwards to the leaves and downwards to the roots. Those of which the pith and medullary plates consist are arranged horizontally, and appear to be intended to maintain a lateral intercourse between the pith and the bark—perhaps even to place the heart of the tree within the influence of the external air.

The root, though prior in its origin to the stem, may nevertheless for the purpose of illustration be considered as its downward and lateral prolongation into the earth—as the branches are its upward prolongation into the air.* When they leave the lower part of the trunk of the tree, they differ little in their internal stucture from the stem itself. As they taper off, however, first the heart wood, then the pith, gradually disappear, till, towards their extremities, they consist only of a soft central woody part and its covering of soft bark. These are connected with, or are respectively prolongations of, the new wood and bark of the trunk and branches. At the extreme points of the roots the bark becomes white, soft, spongy, and full of pores and vessels. It is by these spungy extremities only, or chiefly, that liquid and gaseous substances are capable either of entering into, or of making their escape from, the interior of the root.

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* The correctness of this comparison is proved by the fact that, in many trees, the branch if planted will become a root, and the root if ex-

The branches and twigs are extensions of the trunk; and of the former, the leaves may be considered as a still further extension. The fibres of the leaf are minute ramifications of the woody matter of the twigs, are connected through them with the wood of the branches and stems, and from this wood receive the sap which they contain. The green part of the leaf may be considered as a special expansion of the bark, by which it is fitted to act upon the air, in the same way as the spongy mass into which the bark is changed at the extremity of the root, is fitted to act upon the water and other substances it meets with in the soil. For as the fibres of the leaf are connected with the wood of the stem, so the green part of the leaf is connected with its bark, and from this green part the sap first begins to descend towards the root.

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posed to the air, will gradually be transformed into a branch. The banana in the forest, and the currant tree in our gardens, are familiar instances of trees spontaneously planting their branches, and causing them to perform the functions of roots. In like manner, "if the stem of a young plum or cherry-tree, or of a willow, be bent in the autumn so that one-half of the top can be laid in the earth and one-half of the root be at the same time taken carefully up—sheltered at first and afterwards gradually exposed to the cold—and if the following year the remaining part of the top and root be treated in the same way, the branches of the top will become roots, and the ramifications of the roots will become branches, producing leaves, flowers, and fruit in due season.* The tree is thus reversed in position, and the roots and branches being thus mutually convertible cannot be materially unlike in general structure.

[* Loudon's *Encyclopædia of Agriculture.*]

§ 2. *The functions of the root.*

The position in which the roots of plants in their natural state are generally placed, has hitherto prevented their functions from being so accurately investigated as those of the leaves and of the stem. While, therefore, the main purposes they are intended to serve are universally known and understood, the precise way in which these ends are accomplished by the roots, and the powers with which they are invested, are still to a considerable degree matters of dispute.

I. It appears certain that they are possessed of the power of absorbing water in large quantity from the soil, and of transmitting it upwards to the stem. The amount of water thus absorbed depends greatly upon the nature of the soil and of the climate in which a plant grows, but much also upon the specific structure of its leaves and the extent of its foliage.

II. The analogy of the leaves and young twigs would lead us to suppose that, when in a proper state of moisture, the roots should also be capable of absorbing gaseous substances from the air which pervades the soil. Experiment, however, has not yet shown this to be the case.

We know, however, that they are capable of absorbing gases through the medium of water. For if the roots of a plant are placed in water containing carbonic acid in the state of solution, this gas is found gradually to disappear. It is extracted from the water by the roots. And if the water in which the roots are immersed be contained in a bottle only partially filled with the liquid, while the remainder is occupied by atmospheric air, the oxygen in this air will also slowly diminish. It will be absorbed by the roots through the medium of the water.*

Again, if in the place of the atmospheric air in this bottle, carbonic acid be substituted, the plant will droop and in a few days will die. The same will take place, if instead of common air or carbonic acid, nitrogen or hydrogen gases be introduced into the bottle. The plant will not live when its roots are exposed to the sole action of any of the three.

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* It will be recollected that water absorbs about 4 per cent. of its bulk of air from the atmosphere, of which about one-third is oxygen. If the roots extract this oxygen from the water, the latter will again drink in a fresh portion from the atmospheric air which floats above it.

It is obvious, therefore, that the roots of plants absorb gaseous substances from the air which surrounds their roots, at least indirectly and through the medium of water. It appears also that from this air they have the power of *selecting* a certain portion of oxygen when this gas is present in it. Thirdly, that though they can absorb carbonic acid to a limited amount without injury to the plant, yet that a copious supply of this gas, unmixed with oxygen, is fatal to vegetable life. This deduction is confirmed by the fact that, in localities where carbonic acid ascends through fissures in the subjacent rocks and saturates the soil, the growth of grass is found to be very much retarded. And, lastly, since nitrogen is believed not to be in itself noxious to vegetable life, the death of the plant in water surrounded by this gas, is supposed to imply that the presence of oxygen is necessary about the roots of a growing and healthy plant, and that one of the special functions of the roots is constantly to absorb this oxygen.

This supposition is in accordance with the fact that, in the dark, the leaves of plants absorb oxygen from the atmosphere; for we have already seen reason to expect that, from their analogous structure, the roots and leaves in similar circumstances should perform also analogous functions. At the same time, if the roots do require the access and presence of oxygen in the soil, it would further appear that those of some plants require it more than those of others; inasmuch as some genera, like the grasses, love an open and friable soil, into which the air gains easy admission; while other genera, like the clovers, prefer a denser, stiffer surface, by which the air is more completely excluded.*

III. We have in a former lecture (IV. p. 88) concluded from facts there stated, that solid substances, which are soluble in water, accompany this liquid when it enters into the circulation of the plant. This appears to be true both of organic and inorganic substances. Potash, soda, lime, and magnesia thus find their way into the interior of plants, as well as those substances of animal and vegetable origin to which the observations made in the fourth lecture were intended more especially to apply. Even *silica*,* considered to be almost insoluble in water, enters by the roots, and is found in some cases in considerable quantities in the stem. Some persons have hence been led to conclude that *solid* substances, undissolved, if in a minute state of division, may be drawn into the pores of the root and may then be carried by the sap upwards to the stem.

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* Sprengel, *Chemie*, II., p. 337.

Considered as a mere question of vegetable mechanics, argued as such among physiologists, it is of little moment whether we adopt or reject this opinion. One physiologist may state that the pores by which the food enters into the roots are so minute as to baffle the powers of the best constructed microscope, and, therefore, that to no particles of solid matter can they by possibility give admission—while another may believe solid matter to be capable of a mechanical division so minute as to pass through the pores of the finest membranes. As to the mere fact itself it matters not which is right, or which of the two we follow. The adoption of the latter opinion implies in itself merely that *foreign* substances, unnecessary, perhaps injurious to vegetable life, may be carried forward by the flowing juices until in some still part of the current, or in some narrower vessel, they are arrested and there permanently lodged in the solid substance of the plant.

By inference, however, the adoption of this opinion implies also, that the inorganic substances found in plants,—those which remain in the form of ash when the plant is burned,—are *accidental* only, not *essential* to its constitution. For since they may have been introduced in a mere state of minute mechanical division suspended in the sap, they ought to consist of such substances chiefly as the soil contains in the greatest abundance, and they ought to vary in kind and relative quantity with every variation in the soil. In a clay land the ash should consist chiefly of alumina,* in a sandy soil chiefly of silica. But if, as chemical inquiry appears to indicate, the nature of the ash is not *accidental* but *essential*, and in some degree constant, even in very different soils, this latter inference is inadmissible;—and in reasoning backwards from this fact, we find ourselves constrained to reject the opinion that substances are capable of entering into the roots of plants in a solid state—and this without reference at all to the mechanical question, as to the relative size of the pores of the spongy roots or of the particles into which solid matter may be divided.

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* Silica is the name given by chemists to the pure matter of flint or of rock crystal. Sand and sandstones consist almost entirely of silica.

IV. We are thus brought to the consideration of the alleged selecting power of the roots, which, if rightly attributed to them, must be considered as one of the most important functions of which they are possessed. It is a function, however, the existence of which is disputed by many eminent physiologists. But as the adoption or rejection of it will materially influence our reasonings, as well as our theoretical views, in regard to some of the most vital processes of vegetation,—it will be proper to weigh carefully the evidence on which this power is assigned to the roots of plants.

1°. The leaves, as we shall hereafter see, possess in a high degree the power of selecting from the atmosphere one or more gaseous substances, leaving the nitrogen, chiefly, unchanged in bulk. The absorption of carbonic acid and the diminution of the oxygĕn in the experiments above described, appear to be analogous effects, and would seem to imply in the roots the existence of a similar power.

2°. Dr. Daubeny found that pelargoniums, barley (*hordeum vulgare*), and the winged pea (*lotus tetragonolobus*), though made to grow in a soil containing much strontia,† appeared to absorb none of this earth, for none was found in the ash left by the stem and roots of the plant when burned. In like manner De Saussure observed that polygonum persicaria refused to absorb acetate of lime from the soil, though it freely took up common salt.*

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* Alumina is the pure earth of clay.

† Watered with a solution of nitrate of strontia. Strontia is an earthy substance resembling lime, which is found in certain rocks, and mineral veins, but which has not hitherto been observed in the ashes of plants.

3°. Plants of different species, growing in the same soil, leave, when burned, an ash which in every case contains either different substances, or the same substances in unlike proportions. Thus if a bean and a grain of wheat be grown side by side, the stem of the plant from the latter seed will be found to contain silica, from the former none.†

4°. But the same plant grown in soils unlike in character and composition, contains always—if they are present in the soil at all—very nearly the same kind‡ of earthy matters in nearly the same proportion. Thus the stalks of corn plants, of the grasses, of the bamboo, and of many others, always contain silica, in whatever soil they grow, or at least are capable of growing with any degree of luxuriance.

With the view of testing this point, Lampadius prepared five square patches of ground, manured them with equal quantities of a mixture of horse and cow dung, sowed them with equal measures of the same wheat, and on four of these patches strewed respectively five pounds of finely powdered quartz (siliceous sand), of chalk, of alumina, and of carbonate of magnesia, and left one undressed. The produce of seed from each, in the above order, weighed 24¼, 28¾, 26¼, 21½, and 20 ounces respectively. The grain, chaff, and straw from each of the patches left nearly the same quantity of ash—the weights varying only from 3·7 to 4·08 per cent., and the roots and chaff being richest in inorganic matter. The relative proportions of silica, alumina, lime, and magnesia, were *the same in all.*[*] Provided, therefore, the substances which plants prefer be present in the soil, the kind of inorganic matter they take up, or of ash they leave, is not *materially* affected by the presence of other substances, even in somewhat larger quantity.

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* Liudley's *Theory of Horticulture*, p. 19.

† It is not strictly correct that the bean will absorb *no* silica, but the quantity it will take up will be only one-thirteenth of that taken up by the wheat plant—the per centage of silica in the ash of bean straw being, according to Sprengel, only 0·22, while in wheat straw it is 2·87 per cent. Pea straw contains four times as much as that of the bean, or 0·996 per cent.

‡ For more precise information on this point, see the subsequent lectures, "*On the inorganic constituents of plants.*"

These facts all point to the same conclusion, that the roots have the power of selecting from the soil in which they grow, those substances which are best fitted to promote the growth or to maintain the healthy condition of the plants they are destined to feed.

5°. It has been stated above that the roots of certain plants refuse to absorb nitrate of strontia and acetate of lime, though presented to them in a state of solution—the same is true of certain colored solutions which have been found incapable of finding their way into the circulation of plants whose roots have been immersed in them. On the other hand, it is a matter of frequent observation that the roots absorb solutions containing substances which speedily cause the death of the plant. Arsenic, opium, salts of iron, of lead, and of copper, and many other substances, are capable of being absorbed in quantities which prove injurious to the living vegetable—and on this ground chiefly many physiologists refuse to acknowledge that the roots of plants are by nature endowed with any definite and constant power of selection at all. But this argument is of equal force against the possession of such a power by animals or even by man himself; since, with our more perfect discriminating powers, aided by our reason too, we every day swallow with our food what is more or less injurious, and occasionally even fatal, to human life.[†]

On the whole, therefore, it appears most reasonable to conclude that the roots are so constituted as (1°) to be able generally to select from the soil, *in preference*, those substances which are most suitable to the nature of the plant—(2°) where these are not to be met with, to admit certain others in their stead*—(3°) to refuse admission also to certain substances likely to injure the plant, though unable to discriminate and reject every thing hurtful or unbeneficial which may be presented to them in a state of solution.

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[*] Meyen *Jahresbericht*, 1839, p. 1.

[†] I may here remark that it is by no means an extraordinary power which these circumstances seem to show the roots of plants to possess. In the presence of oxygen, nitrogen, and carbonic acid, in equal quantities, water will prefer and will select the latter. From a mixture of lime and magnesia, acetic or sulphuric acid will select and separate the former. It is unreasonable to suppose the roots of plants—the organs of a living being—to be endowed with the powers of discrimination at least as great as those possessed by dead matter?

The object of nature, indeed, seems to be to guard the plant against the more common and usual dangers only—not against such as rarely present themselves in the situations in which it is destined to grow, or against substances which are unlikely even to demand admission into its roots. How useless a waste of skill, if I may so speak, would it have been to endow the roots of each plant with the power of distinguishing and rejecting opium and arsenic and the thousand other poisonous substances which the physiologist can present to them, but which in a state of nature—on its natural soil and in its natural climate—the living vegetable is never destined to encounter!

V. Another function of the roots of plants, in regard to which physiologists are divided in opinion at the present day, is what is called their *excretory power*.

1°. When barley or other grain is caused to germinate in pure chalk, acetate of lime† is uniformly found to be mixed with it after the germination is somewhat advanced (Becquerel and Mateucci.)‡ In this case the acetic acid must have been given off (excreted) by the young roots during the germination of the seed.

This fact may be considered as the foundation of the excretory theory as it is called. This theory supported by the high authority of Decandolle, and illustrated by the apparently convincing experiments of Macaire,* has more recently been met by counter experiments of Braconnot,† and is now in a great measure rejected by many eminent vegetable physiologists. It may indeed be considered as quite certain that the application of this theory by Decandolle and others to the explanation of the benefits arising from a rotation of crops, is not confirmed, or *proved* to be correct, by any experiments on the subject that have hitherto been published.‡

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* This conclusion is not strictly contained in the premises above stated, but the facts from which it is drawn will be fully explained in treating of the inorganic constituents of plants. It is introduced here for the purpose of giving a complete view of what appears to be the true powers of discrimination possessed by the root.

† Acetate of lime is a combination of acetic acid or vinegar with lime derived from the chalk.

‡ *Ann. de Chim. et de Phys.* lv., p. 310.

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* *Ann. de Chim. et de Phys.* lii., p. 225.

† *Ibid,* lxxii., p. 27.

‡ The discordant results of Macaire and Braconnot were as follow:

1°. Macaire observed that when plants of *Chondrilla Muralis* were grown in rain water they imparted to it something of the smell and taste of opium. Braconnot confirmed this, but attributed it to wounds in the roots which allowed the proper juce of the plant to escape. He says it is almost impossible to free the young roots from the soil in which they have grown, without injuring them and causing the sap to exude.

2°. *Euphorbia Peplus* (Petty Spurge) imparted to the water in which it grew a gummi-resinous substance of a very acrid taste. In the hands of Braconnot it yielded to the water scarcely any organic matter, and that only slightly bitterish.

3°. Braconnot washed the soil in which plants of *Euphorbia Breoni* and *Asclepias Incarnata* were growing in pots, and obtained a solution containing earthly and alkaline salts with only a trace of organic matter.

He also washed the soil in which the Poppy (*Papaver Somniferum*) had been grown ten years successively. The solution besides inorganic earthly and alkaline salts, gave a considerable quantity of acetic acid (in the form of acetate of lime) and a trace of brown organic matter. He infers that these several plants do not excrete any organic matter in sufficient quantity to be injurious to themselves.

4°. Macaire observed that when separate portions of the roots of the same plant of *Mercurialis Annua* were immersed in separate vessels, the one containing pure water and the other a solution of acetate of lead,—the solution of lead was absorbed by the plant—was to be traced in every part of it, and afterwards was partially transmitted to the pure water. Braconnot observed the same results, but he found the entrance of the lead into the second vessel to be owing to the ascent of the fluid up the outer surface of the one root and down the exterior of the other, and that, by preventing the possibility of this passage, no lead could be detected among the pure water.

The conclusions of Macaire, therefore, in favour of the rotation theory of Decandolle must be considered as at present inadmissible, and we shall hereafter see reason to coincide, at least to a certain extent, in the conclusion of Braconnot, "that if these excretions (of organic matter) really take place in the natural state of the plant, they are as yet so

According to Decandolle, plants, like animals, have the power of selecting from their food, as it passes through their vascular system, such portions as are likely to nourish them, and of rejecting, by their roots, when the sap descends, such as are unfit to contribute to their support, or would be hurtful to them if not rejected from their system. He further supposes that, after a time, the soil in which a certain kind of plant grows becomes so loaded with this rejected matter, that the same plant refuses any longer to flourish in it. And, thirdly, that though injurious to the plant from which it has been derived, this rejected matter may be wholesome food to plants of a different order, and hence the advantage to be derived from a rotation of crops.

There seems no good reason to doubt that the roots of plants do at times—it may be constantly—reject organic substances from their roots. The acetic acid given off during germination, and the same acid found by Braconnot in remarkable quantity in the soil in which the poppy (*papaver somniferum*) has grown—may be regarded as a sufficient evidence of the fact—but the quantity of such organic matter hitherto detected among what may be safely viewed as the real excretions of plants, seems by far too small to account for the remarkable natural results attended upon a rotation of crops.

The consideration of these results, as well as of the ge-

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obscure and so little known as to justify the presumption that some other explanation must be given of the general system of rotation." Various illustrations have been given by different observers of this supposed excreting power of the roots. Among the most recent are those of *Nietner*, who ascribes the luxuriant rye crops obtained without manure after three years of clover, to the excretions of this plant in the soil, which like those of the pea and bean to the wheat, he supposes to be nourishing food to the rye. He also states that the beet or the turnip after tobacco has an unpleasant taste, and is scarcely eatable, which he attributes to the excretions of the tobacco plant. Meyen ascribes the effect of the clover to the green manure supplied by its roots and stubble, and that of the tobacco to the undecomposed organic substances contained in the sap and substance of the roots and stems of this plant, of which so large a quantity is left behind in the field.* These objections of Meyen are not without their weight, but we shall hereafter see that they embody only half the truth.

[*Meyens' *Jahresbericht*, 1839, p. 5.]

neral theory of such a rotation, will form a distinct topic of consideration in a subsequent part of these lectures. I shall, therefore, only mention one or two facts which seem to me capable of explanation only on the supposition that the roots of plants are endowed with the power of rejecting, and that they do constantly reject, when the sap returns from the leaf, some of the substances which they had previously taken up from the soil.

1°. De Saussure made numerous experiments on the quantity of ash per cent. left by the same plant at different periods of its growth. Among other results obtained by him, it appeared—

A. That the quantity of incombustible or inorganic matter in the different parts of the plant was different at different periods of the year. Thus the dry leaves of the horse chestnut, gathered in May, left 7·2 per cent., towards the end of July 8·4 per cent., and in the end of September 8·6 per cent. of ash; the dry leaves of the hazel in June left 6·2, and in September 7 per cent.; and those of the poplar (*populus nigra*) in May 6·6, and in September 9·3 per cent. of ash. These results are easily explained on the supposition that the roots continued to absorb and send up to the leaves during the whole summer the saline and earthy substances of which the ash consisted. But—

B. He observed also that the quantity of the inorganic substances in—or the ash left by—the *entire* plant, diminished as it approached to maturity. Thus the dry plants of the vetch, of the golden rod (*solidago vulgaris*), of the turnsol (*helianthus annuus*), and of wheat, left respectively of ash, at three different periods of their growth*—

	Before flowering. *per cent.*	In flower. *per cent.*	Seeds ripe. *per cent.*
Vetch	15	12·2	6·6
Golden rod	9·2	5·7	5·0
Turnsol	14·7	13·7	9·3
Wheat	7·9	5·4	3·3

This diminution in the proportion of ash, might arise either from an increase in the absolute quantity of vegetable matter in the plants accompanying their increase in size—or from a portion of the saline and earthy matters they contained being again rejected by the roots. But if the former be the true explanation, the *relative proportions* of the several substances of which the ash itself consisted, in the several cases, should have been the same at the several periods when the experiments were made. But this was by no means the case. Thus, to refer only to the quantity of silica contained in the ash left by each of the above plants at the several stages of their growth, the ashes of the

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* Davy's *Agricultural Chemistry*, Lecture III.

	Before flowering. *per cent.*	In flower. *per cent.*	Seeds ripe. *per cent.*
Vetch contained	1·5	1·5	1·75
Golden rod	1·5	1·5	3·5
Turnsol	1·5	1·5	3·75
Wheat	12·5	26·0	51·0

If, then, the proportion of silica in the ash increased in some cases four-fold, while the whole quantity of ash left by the plant decreased, it appears evident that some part of that which existed in the plant during the earlier periods of its growth must have been excreted or rejected by the roots, as it advanced towards maturity.

2°. This conclusion is confirmed and carried farther by another consideration. The quantity of ash left by the ripe wheat plant, in the above experiments of De Saussure, amounted to 3·3 per cent.;—of which ash, 51 per cent., or rather more than one-half, was silica. This silica, it is believed, could only have entered into the circulation of the plant in a state of solution in water, and could only be dissolved by the agency of potash or soda. But according to Sprengel, the potash, soda, and silica, are to each other in the grain and straw of wheat, in the proportions of—

	Potash.	Soda.	Silica.
Grain	0·225	0·24	0·4
Straw	0·20	0·29	2·87

Or, supposing the grain to equal one-half the weight of the straw—their relative proportions in the whole plant will be nearly as, 21 potash, 27 soda, 205 silica, or the weight of the silica is upwards of four times the weights of the potash and soda taken together.

Now silica requires nearly half its weight of potash to render it soluble in water,[*] or three-fifths of its weight of a mixture of nearly equal parts of potash and soda. The quantity of these *alkaline* substances *found* in the plant, therefore, is by no means sufficient to have dissolved and brought into its circulation the whole of the silica it contains. One of two things, therefore, must have taken place. Either a portion of the potash and soda present in the plant in the earlier stages of its growth must have escaped from its roots at a later stage,[†] leaving the silica behind it—or the same quantity of alkali, must have circulated through the plant several times—bringing in its burden of silica, depositing it in the vascular system of the plant, and again returning to the soil for a fresh supply. In either case the roots must have allowed it egress as well as ingress. But the fact, that the *proportion* of silica in the plant goes on increasing as it continues to grow, is in favour of the latter view—and renders it very probable that the same quantity of alkali returns again and again into the circulation, bringing with it supplies of silica and probably of other substances which the plant requires from the soil. And while this view appears to be the more probable, it also presents an interesting illustration of what may *probably* be the kind of function discharged by the potash and other inorganic substances found in the substance of plants—a question we shall hereafter have occasion to consider at some length.

The above considerations, therefore, to which I might add others of a similar kind, satisfy me that the roots of plants *do possess* the power of excreting various substances which are held in solution by the sap on its return from the stem —and which having performed their functions in the interior of the plant are no longer fitted, in their existing condition, to minister to its sustenance or growth. Nor is it likely that this excretory power is restricted solely to the emission of inorganic substances. Other soluble matters of organic origin are, no doubt, permitted to escape into the soil—though whether of such a kind as must necessarily be injurious to the plant from which they have been extruded, or to such a degree as *alone* to render a rotation of crops necessary, neither reasoning nor experiment has hitherto satisfactorily shown.

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[*] A soluble *glass* may be made by melting together in a crucible for six hours 10 parts of carbonate of potash, 15 of silica, and 1 of charcoal powder.

[†] De Saussure does not state the *exact* relative quantities of potash and soda at the several periods of the growth of wheat, though they appear to have gradually diminished. It seems, indeed, to be true of many plants, that the potash and soda they contain diminishes in quantity as their age increases. Thus the weight of potash in the juice of the ripe or sweet grape, is said to be less than in the unripe or sour grape—and the leaves of the potato have been found more rich in potash before than after blossoming (Liebig).

VI. The roots have the power of absorbing, and in some measure of selecting, food from the soil—can they also modify or alter it as it passes through them ? A colourless sap is observed to ascend through the roots. From the very extremity up to the foot of the stem a cross section exhibits little trace of colouring matter, even when the soil contains animal and vegetable substances which are soluble, and which give dark coloured solutions.* Does such matter never enter the root ? If it does, it must be speedily changed or transformed into new compounds.

We have as yet too few experiments upon this subject to enable us to decide with any degree of certainty in regard to this function of the root. It is probable, however, that as the sap passes through the plant, it is constantly, though gradually, undergoing a series of changes, from the time when it first enters the root till it again reaches it on its return from the leaf.

Can we conceive the existence of any powers in the root, or in the whole plant, of a still more refined kind ? The germinating seed gives off acetic acid into the soil,—does this acetic acid dissolve lime from the soil and return with it again, as some suppose (Liebig), into the circulation of the plant ?† Is acetic acid produced and excreted by the seed for this very refined purpose? We have concluded that in the wheat plant the potash and soda probably go and come several times during its growth, and the ripening of its seed. Is this a contrivance of nature to make up for the scarcity of alkaline substances in the soil—or would the same mode of operation be employed if potash and soda were present in greater abundance? Or where the alkalies are present in greater abundance, might not more work be done by them in the same time,—might not the plant be built up the faster and the larger, when there were more hands, so to speak, to do the work? Is the action of inorganic substances upon vegetation to be explained by the existence of a power resident in the roots or other parts of plants, by which such operations as this are directed or superintended? There are many mysteries connected with the nature and phenomena of vegetable life, which we have been unable as yet to induce nature to reveal to us.[*] But the morning light is already kindling on the tops of the mountains, and we may hope that the deepest vallies will not forever remain obscure.

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* Such as the liquid manure of the fold-yard.

† Braconnot found acetate of lime in very small quantities to be singularly hurtful to vegetation, and acetate of magnesia a little less so. He only mentions, however, some experiments upon *mercurialis annua*,‡ and as Saussure found that some plants actually refuse to take it up at all, these acetates may not be equally injurious to all plants.

[‡ *Ann de Chim. et de Phys.* lxxii., p. 36.]

§ 3. *The course of the sap.*

If a trunk of a tree be cut off above the roots, and the lower extremity be immediately plunged into a solution of madder or other colouring substance, the coloured liquid will ascend and will gradually tinge the wood. This ascent will continue till the colour can also be observed in the nerves of the leaf. If at this stage in the experiment the trunk be cut across at various heights, the wood alone will appear coloured, the bark remaining entirely untinged. But if the process be allowed still to continue when the colouring matter has reached the leaf, and after some further time the stem be cut across, the bark also will appear dyed, and the tinge will be perceptible further and further from the leaf the longer the experiment is carried on, till at length both bark and wood will be coloured to the very bottom of the stem.

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[*] The roots of trees will travel to comparatively great distances, and in various directions in search of water: the roots of Sainfoin (*Esparsette*) will penetrate 10 or 12 feet through the calcareous rubby subsoil, or down the fissures of limestone rocks on which they delight to grow. Is this the result of some *perceptive* power in the plant—or is it merely by *accident* that the roots display these tendencies?

Those who are in any degree acquainted with the speculations of the German physiologists of the greatest name—in regard to the *soul* and even the *immortality* of plants—will not accuse me of going *very* far in alluding to the impossible existence of some such perceptive power in plants. Von Martius gets rid of objectors by speaking of them as "*scientific men to whom the power of comprehending the transcendental has been imparted in a lower degree.*"—See Meyen's *Jahresbericht*, 1839, or *Silliman's American Journal for January*, 1841, p. 170.

Or of the root of a living plant, as in the experiment of Macaire detailed in the preceding note, be immersed in a metallic solution—such as a solution of acetate of lead,—which it is capable of absorbing without immediate injury, and different portions of the plant be examined after the lapse of different periods of time,—first the stem, afterwards the leaves, then the bark of the upper part of the stem, and lastly that of the lower part of the stem, will exhibit traces of lead.

These experiments show that the sap which enters by the roots ascends through the vessels of the wood, diffuses itself over the surface of the leaves, and then descends by the bark to the extremities of the root.

But what becomes of the sap when it reaches the root? Is it delivered into the soil, or does it recommence the same course, and again, repeatedly perhaps, circulate through the stem, leaves, and bark? This question has been partly answered by what has been stated in the preceding section. When the sap reaches the extremity of the root, it appears to give off to the soil both solid and fluid substances of a kind and to an amount which probably differ with every species of plant. The remainder of the sap and of the substances it holds in solution must be diffused through the cellular spongy terminations of the roots, and, with the new supply of liquid imbibed from the soil, returned again to the stem with the ascending current.

But what causes the sap thus to ascend and descend? By what power is it first sucked up through the roots, and afterwards forced down again from the leaves? Several answers have been given to this question.

1°. When the end of a wide tube, either of metal or of glass, is plunged into water, the liquid will rise within the tube sensibly to the same level as that at which it stands in the vessel. But if a *capillary*[*] tube be employed instead of one with a wide bore, the liquid will rise, and will permanently remain at a considerably higher level within than without the tube. The cause of this rise has been ascribed to an attraction which the sides of the tube have for the liquid, and which is sufficiently strong to raise it and to keep it up above the proper level of the water. The force itself is generally distinguished by the name of *capillary attraction*.

Now, the wood of a tree, as we have seen, is composed of a mass of fine tubes, and through these the sap has been said to rise by *capillary attraction*. But if the top of a vine be cut off when it is juicy and full of sap, the liquid will exude from the newly formed surface, and if the air be excluded, will flow for a length of time, and may be collected in considerable quantity.[†] Such a flow of the sap is not to be accounted for by mere capillary attraction—the sides of tubes cannot draw up a fluid beyond their own extremities.

2°. To supply the defect of this hypothesis, De Saussure supposed that the fluid at first introduced by capillary attraction into the extremities of the root, was afterwards propelled upwards by the alternate contraction and expansion of the tubes of which the wood of the root and stem is composed. This alternate contraction and expansion he also supposed to be caused by a peculiar *irritating* property of the sap itself, which caused each successive part of the tube into which it found admission to contract for the purpose of expelling it. Mr. Knight also ascribed the ascent of the sap to a similar contraction of certain *other* parts of the stem. Being once raised, he supposed it to return again or descend by its own weight—but in drooping branches it is obvious that the sap must be actually driven or drawn upwards from the leaves on its return to the root. These explanations, therefore, are still unsatisfactory.

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[*] Glass tubes perforated by a very fine bore, like a human hair, are called *capillary* tubes. Such are those of which thermometers are usually made.

[†] Lindley's *Theory of Horticulture*, p. 47 (note).

3°. If one end of an open glass tube be covered with a piece of moistened bladder or other fine animal membrane, tied tightly over it, and a strong solution of sugar in water be then poured into the open end of the tube, so as to cover the membrane to the depth of several inches, and if the closed end be then introduced to the depth of an inch below the surface of a vessel of pure water, the water will after a short time pass through the bladder inwards, and the column of liquid in the tube will increase in height. This ascent will continue, till in favourable circumstances the fluid will reach the height of several feet, and will flow out or run over at the open end of the tube. At the same time the water in the vessel will become sweet, indicating that while so much liquid has passed through the membrane inwards, a quantity has also passed outwards, carrying sugar along with it.* To these opposite effects *Dutrochet*, who first drew attention to the fact, gave the names of *Endosmose*, denoting the inward progress, and *Exosmose*, the outward progress of the fluid. He supposed them to be due to the action of two opposite currents of electricity, and he likens the phenomena observed during the circulation of the sap in plants, to the appearances presented during the above experiment.

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* Instead of sugar, common salt, gum, or other soluble substances may be dissolved in the water introduced at first into the tube, and the denser this solution the larger the quantity of water which will enter by the membrane, and the greater the height to which the column will rise. It ceases in all cases to rise only when the portions of liquid within and without the membrane attain nearly to the same density.† Instead of pure water the vessel into which the extremity of the tube is plunged may also contain a weak solution of some soluble substance—such as lime or soda—in which case, while the sugar, or salt, or gum, will pass outwards in smaller quantity, the lime or soda will pass inwards, along with the currents of water in which they are severally dissolved.

[† Contain nearly the same weight of solid matter in solution.]

Without discussing the degree of probability which exists as to the influence of electricity in producing the phenomena of endosmose and exosmose, it must be admitted that the appearances themselves bear a strong resemblance to those presented in the absorption and excretion of fluids by the roots of plants—and point very distinctly to at least a kindred cause.

Thus, if the spongy termination of the root represent the thin porous membrane in the above experiment—the sap with which the tubes of the wood are filled, the artificial solution introduced into the experimental tube—and the water in the soil, the water or aqueous solution into which the closed extremity of the tube is introduced, —we have a series of conditions precisely similar to those in the experiment. Fluids ought, consequently, to enter from the soil into the roots, and thence to ascend into the stem, as in nature they appear to do.

This ascent, we have said, will continue till the fluid in the tubes of the wood (the sap) is reduced to a density as low as that of the liquid entering the roots from the soil. But in a growing tree, clothed with foilage, this will never happen. The leaves are continually exhaling aqueous vapour, as one of their constant functions, and sometimes in very large quantity. The sap, therefore, when it reaches the leaves, is concentrated or thickened, and rendered more dense by the separation of the water, so that when it descends to the root, and again begins its upwards course, it will admit of large dilution before its density can be so far diminished as to approach that of the comparatively pure water which is absorbed from the soil. And this illustration of the ascent of the sap appears the more correct from the obvious purpose it points out—(in addition to others long recognised)—as served by the evaporation which is constantly taking place from the surface of the leaf.

Still the cause of the ascent of the sap is not the more clear that we can imitate it in some measure by an artificial experiment. But it will be conceded by the strictest reasoners on physical phenomena, that to have obtained the command, or even a partial control, over a natural power, is a considerable step towards a clear conception of the nature of that power itself. If the phenomena of endosmose can hereafter be clearly and indubitably traced to the agency of electricity, we shall have advanced still another step, and shall be enabled to devise other means by which a more perfect imitation of nature may be effected, or a more complete control asserted over the phenomena of vegetable circulation.

§ 4. *Functions of the stem.*

The functions of the stem are probably as various as those of the root, though the circumstances under which they are performed necessarily involve these functions in considerable obscurity.

The pith which forms the central part of the stem consists, as I have already stated, of tubes disposed horizontally. When a coloured fluid is permitted to enter the lower part of the stem in the experiments above described, the pith remains untinctured in the centre of the coloured wood. It does not, therefore, serve for the conveyance of the sap. Nor does it seem to be vitally necessary to the health and growth of the plant, since Mr. Knight has shown that, from the interior of many trees, it may be removed without apparent injury, and in nature, as trees advance in age, it gradually diminishes in bulk, and in some species becomes apparently obliterated.

The vessels of the wood, which surrounds the pith, perform probably both a mechanical and a chemical function. They serve to convey upwards to the leaf the various substances which enter by the roots. This is their mechanical function. But during its progress upwards, the sap appears to undergo a series of changes. When it reaches the leaves it is no longer in the state in which it is ascended from the root into the stem. The difficulty of extracting the sap from the wood, at different heights, has prevented very rigorous experiments from being made on its nature and contents at the several stages of its ascent. These it is obvious must vary with the species and age of the plant, and with the season of the year at which the experiment is made. But the general result to be drawn from such observations as have hitherto been made, is, that those substances which enter directly into the root, when mingled with such as have already passed through the circulation of the plant, undergo, during their ascent, a gradual preparation for that state in which they become fit to minister to the growth of the plant. This preparation is completed in a great measure in the leaf, though further changes still go on as the sap descends through the bark. This deduction is strengthened by the fact that gaseous substances of various kinds and in varying quantities exist in the interior of the wood of the growing plant. These gaseous substances, according to Boucherie, are in some cases equal in bulk to one-twentieth part of the entire trunk of the tree in which they exist. They probably move upwards along with the sap, and are more or less completely discharged into the atmosphere through the pores of the leaves. That these gaseous substances not only differ in quantity, but in kind also, with the age and species of the tree, and with the season of the year, may, I think, be considered as almost amounting to a proof that they have not been inhaled directly by the roots, but are the result of chemical decompositions which have taken place on the stem itself, as the sap mounted upwards towards the leaves.

We have seen that the roots exercise a kind of discriminating power in admitting to the circulation of the plant the various substances which are present in the soil. The vessels of the stem exhibit an analogous power of admitting or rejecting the solutions of different substances into which they may be immersed. Thus Boucherie states that, when the trunks of several trees of the same species are cut off above the roots and the lower extremities immediately plunged into solutions of different substances, some of these solutions will quickly ascend into and penetrate the entire substance of the tree immersed in them, while others will not be admitted at all, or with extreme slowness only, by the vessels of the stem to which they are respectively presented. On the other hand, that which is rejected by one species will be readily admitted by another. Whether this partial stoppage of, or total refusal to admit, certain substances, be a mere *contractile* effort on the part of the vessels, or be the result of a chemical change by which their exclusion is effected or resisted, does not as yet clearly appear. That it does not depend upon the lightness and porosity of the wood, as might be supposed, is shown by the observation that the poplar is less easily penetrated in this way than the beech, and the willow than the pear tree, the maple, or the plane.

These various functions of the woody part of the stem are performed chiefly by the newer wood or *alburnum*, or, as it is often called, the sap wood of the tree. As the heart wood becomes older, the tubes of which it consists are either gradually stopped up by the deposition of solid substances which have entered by the roots, or by the formation of chemical compounds, which, like concretions in the bodies of animals, slowly increase in size till the vessels become entirely closed—or they are by degrees compressed literally by the growth of wood around them, so as to become incapable of transmitting the ascending fluids. Perhaps the result is in most cases due in part to both these causes. This more or less perfect stoppage of the oldest vessels is one reason why the course of the sap is chiefly directed through the newer tubes.*

The functions of the bark, which forms the exterior portion of the stem, will be more advantageously described, after we shall have considered the purposes served by the leaves.

§ 5. *Functions of the leaves.*

The vessels of which the sap wood is composed extend upwards into the fibres of the leaf. Through these vessels the sap ascends, and from their extremities diffuses itself over the surface of the leaf. Here it undergoes important chemical changes, the extent, if not the exact nature, of which will appear from a short description of the functions which the leaves are known or are believed to discharge.

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* As the newest roots are prolongations of the newest wood, it may be supposed that the fact of these roots being the chief absorbents from the soil, is a sufficient reason why that which is absorbed by them should also pass up through the wood with which they are most closely connected. But that the pores of the heart wood are really incapable of transmitting fluids, is shown by plunging the newly cut stem of a tree into a coloured solution,—the newer wood will be dyed, while more or less of the central portion will remain unchanged.

1°. When the roots of a living plant are immersed in water, it is a matter of familiar observation that the water gradually diminishes in bulk, and will at length entirely disappear, even when evaporation into the air is entirely prevented. The water which thus disappears is taken up by the roots of the plant, is carried up to the leaves, is there spread out over a large surface exposed to the sun and to the air, and in the form of vapour escapes in considerable proportion through the pores of the leaves and diffuses itself through the atmosphere.

The quantity of water which thus escapes from the surface of the leaves varies with the moisture of the soil, with the species of plant, with the temperature and moisture of the air, and with the season of the year. According to the experiments of Hales, it is also dependent on the presence of the sun, and is scarcely perceptible during the night. He found that a sun-flower, 3½ feet high, lost from its leaves during 12 hours of one day 30, and of another day 20 ounces of water, while during a warm night, without dew, it lost only three ounces, and in a dewy night underwent no diminution in weight.*

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* When the escape of vapour from the leaves is more rapid than the supply of water from the roots, the leaves droop, dry and wither. Such is sometimes the case with growing crops in very hot weather, and it always happens when a twig or flower is plucked and separated from the stem or root. When thus separated the leaves still continue to give off watery vapour into the air, and consequently the sap ascends from the twig or stalk to supply the place of the water thus exhaled.

But as the sap ascends it must leave the vessels empty of fluid, and air must rush in to fill the empty space. This will continue till nearly all the fluid has risen from the stem into the leaf, and the vessels of the wood are full of air. But if the stem of the twig or flower be placed in water, this liquid will rise into it, air will be excluded, and the freshness and bloom of the leaves and flowers will be longer preserved. If the water into which they are introduced contain any substance in solution, these will rise along with the water, and will gradually make their way through all the vessels of the wood, till they can be detected in the leaves. By this means even large trees may in a short time be saturated with saline solutions, capable of preserving them from decay. It is only necessary to cut down or saw through the tree and insert its lower extremity into the prepared solution, when the action of the sun and air upon the leaves

This loss of watery vapour by the leaf is ascribed to two different kinds of action. First, to a natural perspiration from the pores of the leaf, similar to the insensible perspiration which is continually proceeding from the skins of healthy animals; and second, to a mechanical evaporation like that which gradually takes place from the surface of moist bodies when exposed to hot or dry air. The relative amount of loss due to each of these two modes of action respectively, must differ very much in different species of plants, being dependent in a great measure on the special structure of the leaf. In all cases, however, the natural perspiration is believed very greatly to exceed the mere mechanical evaporation—though the results of Hales, and of other experimenters, show that both processes proceed with the greatest rapidity under the influence of a warm dry atmosphere, aided by the direct rays of the sun.

Among the several purposes served by this escape of watery vapour from the surface of the leaf, it is of importance for us to notice the direct chemical influence it exercises over the growth of the plant. As the water disappears from the leaf, the roots must absorb from the soil at least an equal supply. This water brings with it the soluble substances, organic and inorganic, which the soil contains, and thus in proportion to the activity with which the leaves lose their watery vapour, will be the quantity of those substances which enter from the soil into the general circulation of the plant. This enables us to understand how substances, very sparingly soluble in water, should yet be found in the inte-

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will cause it spontaneously to ascend. Thus *corrosive sublimate* (the subject of Kyan's Patent) may be injected with ease, or *pyrolignite of iron*, (iron dissolved in wood vinegar,) which Boucherie recommends as equally efficient and much more economical.* The process is finished when the liquid is found to have risen to the leaf. Coloured solutions may in the same way be injected and the wood tinged to any required shade. One of the chief benefits attendant upon the cutting of wood in the winter, appears to be that the absence of leaves prevents the exhaustion of the sap and the ascent of air into the vessels of the wood—the oxygen of this air tending to induce decay. But the sap may be retained, and the air excluded almost as effectually, at any other season of the year, by stripping the tree of its leaves and branches a few days before it is cut down.

[* *Ann. de Chim. et de Phys.* lxxiv. p. 113.]

rior of plants, and in very considerable quantity, at almost every stage of their growth.

2°. Besides watery vapour, however, the leaves of nearly all plants exhale at the same time other volatile compounds in greater or less abundance. In the petals of flowers we are familiar with such exhalations—often of an agreeable and odoriferous character. In the case of plants and trees also which emit a sensible odour, we readily recognise the fact of volatile substances being given off by the leaves. But even when the sense of smell gives us no indication of their emission from a single leaf or a single plant, the introduction of a number of such inodorous plants into the confined atmosphere of a small room after a time satisfies us that even they part with some volatile matter from their leaves, which makes itself perceptible to our imperfect organs only when in a concentrated state. The probability therefore is, that the leaves of all plants emit, along with the watery vapour which they evolve, certain other volatile substances also, though often in quantities so minute as to escape detection by our unaided senses. By the emission of these substances the plant probably relieves itself of what would prove injurious if retained, though of the chemical nature and composition of these exhalations little or nothing has as yet been ascertained.

3°. If the branch of a living plant be so bent that some of its leaves can be introduced beneath the edge of an inverted tumbler full of water, and if the leaves be then exposed to the rays of the sun, bubbles of gas will be seen to form on the leaf, and gradually to rise through the water and collect in the bottom of the tunbler. If this gas be examined it will be found to be pure oxygen.

If the water contain carbonic acid gas, or if during the experiment a little carbonic acid be introduced, this gas will be found gradually to disappear, while the oxygen will continue to accumulate.

Or if the experiment be made by introducing a living plant into a large bell glass full of common atmospheric air, allowing it to grow there for 12 hours in the sunshine, and then examining or analysing the air contained in the glass, the result will be of a precisely similar kind. The per centage of oxygen in the air will have increased.* And if the experiment be varied by the introduction of a small quantity of carbonic acid gas into the jar, this gas will be found as before to diminish in quantity, while the oxygen increases. The conclusion drawn from these experiments, therefore, is, that *the leaves of plants, when exposed to the rays of the sun, absorb carbonic acid from the air and give off pure oxygen gas.*

It has been already stated that the proportion of carbonic acid present in the atmosphere is exceedingly small,† but if for the purpose of experiment we increase this proportion in a gallon of air to five or ten per cent., introduce a living plant into it, and expose it to the sunshine, the carbonic acid will gradually disappear as before, while the oxygen will increase. And if we analyse the air and estimate the exact bulk of each of these gases present in it at the close of our experiment, we shall find that the oxygen has increased generally by as much as the carbonic acid has diminished. That is to say, if five cubic inches of the latter have disappeared, five cubic inches will have been added to the bulk of the oxygen. The above general conclusion, therefore, is rendered more precise by this experiment, which appears to show *that under the influence of the sun's rays the leaves of plants absorb carbonic acid from the air and at the same time give off* AN EQUAL BULK *of oxygen gas.*

And as carbonic acid (CO^2) contains its own bulk of oxygen gas‡ combined with a certain known weight of carbon, it is further inferred that the oxygen given off by the leaves is the same which has been [previously absorbed in the form of carbonic acid, and therefore it is usually stated as a function of the leaves—that *in the sunshine they absorb carbonic acid from the air,* DECOMPOSE *it in the interior of*

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* It will be remembered that atmospheric air contains about 21 per cent. of oxygen gas.

† About 1-2500th of its bulk. See Lecture II., p. 36.

‡ This the reader will recollect is proved by burning charcoal in a bottle of oxygen gas till combustion ceases, when nearly the whole of the oxygen is converted into carbonic acid, but without change of bulk. See Lecture III., p. 57.

the leaf, retain its carbon, and again reject or emit the oxygen it contained.

This conclusion presents a very simple view of the relations of oxygen and carbonic acid respectively to the living leaf in the presence of the sun, and it appears to be fairly deduced from the facts above stated. It has occasionally been observed, however, that the bulk of oxygen given off by the leaf has not been precisely equal to that of the carbonic acid absorbed,* and hence it is also fairly concluded that a portion of the oxygen of the carbonic acid which enters the leaf is retained, and made available in the production of the various substances which are formed in the vascular system of different plants. On the other hand it is stated by Sprengel, that if compounds containing much oxygen be presented to the roots of plants, and thus introduced into the circulation, they are also decomposed, and the oxygen they contain in part or in whole given off by the leaves, so that, under certain circumstances, the bulk of the oxygen which escapes is actually greater than that of the carbonic acid which is absorbed by the leaves. Such is the case, for example, when the roots are moistened with water containing carbonic, sulphuric, or nitric acids.†

It is of importance to note these deviations from apparent simplicity in the relative bulks of the two gases which are respectively given off and absorbed by all living vegetables. There are numerous cases of the formation of substances in the interior of plants which theory would fail to account for with any degree of ease, were these apparent anomalies to be neglected. This will more distinctly appear when in a subsequent lecture we shall inquire *how* or by what chemical changes the substances which plants contain, or of which they consist, are produced from the food which they draw from the air and from the soil.

The most general and probable expression, therefore, for the function of the leaf, now under consideration, appears to be that in the sunshine the leaves absorb from the air carbonic acid, and at the same time evolve oxygen gas, the bulk of the latter gas given off being nearly equal to that of the former which is taken in—the relative bulks of the two gases varying more or less with the species of plant, as well as with the circumstances under which it is caused or is fitted to grow.*

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* See Persoz *Chimie Moleculaire*, p. 54.

† Sprengel *Chemie*, II., p. 344.

4°. Such is the relation of the leaf to the oxygen and carbonic acid of the atmosphere in the presence of the sun. During the night their action is reversed, they *emit carbonic acid and absorb oxygen.* This is proved by experiments similar to those above described. For if the plant which has remained under the bell glass for 12 hours in the sunshine—during which time the oxygen has sensibly increased, and the carbonic acid diminished in bulk—be allowed to remain in the same air through the following night, the oxygen will be found to have decreased, while the carbonic acid will be present in larger quantity than in the evening of the previous day.

The carbonic acid thus given off during the night is supposed to be partly derived from the soil through the roots, and partly from the substance of the plant itself. The oxygen absorbed either combines with the carbon of the plant to form a portion of the carbonic acid which is at the same time given off, or is employed in producing some of the other *oxidized*† compounds that exist in the sap.

As a general rule, the quantity of carbonic acid given off during the night is far from being equal to that which is absorbed during the day. Still it is obvious that a plant loses carbon precisely in proportion to the amount of this gas given off. Hence, when the days are longest, the plant will lose the least, and where the sun is brightest it will gain the fastest; since other things being equal, the decomposition of carbonic acid proceeds most rapidly where the sky is the clearest, and the rays of the sun most powerful. Hence we see why in Northern regions, where spring, summer, and autumn are all comprised in one long day—vegetation should proceed with such rapidity. The decomposition of the carbonic acid goes on without intermission, the leaves have no night of rest, but nature has kindly provided that, where the season of warmth is so fleeting, there should be no cessation to the necessary growth of food for man and beast.

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* As the oxygen given off by the leaves is always the result of a chemical decomposition, by which the carbonic acid or other compound is deprived of a portion, at least, of its oxygen or *de*-oxidized, this function of the leaves in the presence of the sun is often spoken of as their *de-oxodizing* power.

† *Oxidized*—containing oxygen in considerable quantity.

This comparison of the functions performed by the leaf, during the day and night respectively, explains the chemical nature of the *blanching* of vegetables practised by the gardener, as well as the cause of the pale colour of plants that grow naturally in the absence of light.

When exposed to the sun, the leaves of these sickly vegetables evolve oxygen, and gradually become green and healthy. Woody matter is formed, and their stems become strong and fibrous.

The light of the sun, in the existing economy of nature, is indeed equally necessary to the health of plants and of animals. The former become pale and sickly, and refuse to perform their most important chemical functions when excluded from the light. The bloom disappears from the human cheek, the body wastes away, and the spirit sinks, when the unhappy prisoner is debarred from the sight of the blessed sun. In *his* system, too, the presence of light is necessary to the performance of those *chemical* functions on which the healthy condition of the vital fluids depends.

The processes by which oxygen and carbonic acid are respectively evolved in plants have been likened by physiologists to the respiration and digestion of animals. It is supposed that when plants respire they give off carbonic acid as animals do, and that when they digest they evolve oxygen. Respiration also, it is said, proceeds at all times, digestion only in the light of the sun. Though these views are confessedly conjectural, they are founded upon striking analogies, and may reasonably be entertained as matters of opinion.

6°. Other species of decomposition also, besides that of *de-oxidization*, go on in the leaf, or are there made manifest. Thus when plants grow in a soil containing much common salt (chloride of sodium) or other chlorides, they have been observed by Sprengel and Meyen to evolve chlorine* gas from their leaves. This takes place, however, more during the night than during the day. Some plants also give off ammonia, (Lecture IV., p. 98,) while others (cruciferæ), according to Dr. Daubeny,† emit from their leaves pure nitrogen gas.

The evolution of chlorine implies the previous decomposition of the chlorides, which have been absorbed from the soil; while that of nitrogen may be due to the decomposition of ammonia, of nitric acid, or of some other compound containing nitrogen, which has entered into the circulation by the roots. The exact mode and nature of the decomposition of these substances, and the purposes served by them in the vegetable economy, will come under our consideration in a subsequent lecture.

The leaf has been described (p. 107) as an expansion of the bark. It consists internally of two layers of veins or vascular fibres laid one over the other, the upper connected with the wood—the lower with the inner bark. It is covered on both sides by a thin membrane (epidermis) the expansion of thé outer bark. This thin membrane is studded with numerous small pores or mouths (stomata) which vary in size and in number with the nature of the plant, and with the circumstances in which it is intended to grow. It is from the pores in the upper part of the leaf that substances are supposed to be exhaled, while every thing that is inhaled enters by those which are observed in the under side of the leaf.‡ This opinion, however, is not universally received, it being admitted by some that the power both of absorbing and of emitting may be possessed by the under surface of the leaf.

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* Chlorine is a gas of a greenish yellow colour, having an unpleasant taste and a suffocating odour. When it combines with other substances it forms *chlorides*. It exists in, and imparts its smell to, *chloride of lime*, which is employed for disinfecting purposes, and it forms upwards of half the weight of common salt.

† *Three Lectures on Agriculture*, p. 59.

‡ This is illustrated by the action of a cabbage leaf on a wound. If the upper side be applied, the sore is protected and quickly heals, while the under side *draws* it and produces a constant discharge.

7°. We have seen that the chief supply of the fluids which constitute the sap of plants, is derived from the soil. The under side of the leaves of plants is also supposed by some to be capable of absorbing moisture from the air, either in the form of watery vapour, or when it falls upon the leaves in the state of dew. Like the roots also they may absorb with the dew any substances the latter happens to hold in solution. And thus plants may, in some degree, be nourished by the volatile organic substances which ascend from the earth during the heat of the day, and which are again in a great measure precipitated with the evening dew.

Whether the leaves ever absorb nitrogen gas from the air has not as yet been determined with sufficient accuracy. If they do, it must in general be in very small quantity only, since it has hitherto escaped detection. In like manner it is doubtful how far they regularly absorb any other substances which the air is supposed to contain. Thus it is known that nitric acid exists in the air in very minute quantity. Some chemists also believe that ammonia is extensively diffused through the atmosphere in an exceedingly diluted state. Do the leaves of plants absorb these substances? Is the absorption of them one of the constant and necessary functions of the leaves? The reply to these questions must be very uncertain, and any principle which professes to be based upon such a reply must be regarded only as a matter of opinion.

8°. The petals or flower-leaves perform a somewhat different function from those of the ordinary leaves of a plant. They absorb oxygen at all times—though more by day than by night—and they constantly emit carbonic acid. The bulk of the latter gas evolved, however, is less than that of the oxygen taken in. The absorption of oxygen gas, and the constant production of carbonic acid, is, in some flowers, so great as to cause a perceptible increase of temperature—and to this slow combustion, so to speak, the proper heat observed in the flowers of many plants has been attributed.

According to some authors, the flower-leaves also emit pure nitrogen gas.* This fact has not yet been determined by a sufficient number of accurate experiments; it is in accordance, however, with the results of Boussingault that, when a plant flowers and approaches to maturity, the nitrogen it contains becomes less. If confirmed, this evolution of nitrogen would throw an interesting light on the most advantageous employment of green crops, both for the purposes of manure and for the feeding of cattle.

9°. When the leaves of a plant begin to decay, either naturally as in the autumn, or from artificial or accidental causes, they no longer absorb and decompose carbonic acid, even under the influence of the sun's rays. On the contrary, they absorb oxygen, like the petals of the flower, new compounds are formed within their substance—their green colour disappears—they become yellow—they wither, die, and drop from the tree—their final function, as the organs of a living being, is discharged. They then undergo new changes, are subjected to a new series of influences, and are made to serve new purposes in the economy of nature. These we shall hereafter find to be no less interesting and important in reference to a further end, than are the functions of the living leaf to the growth and nourishment of the plant.†

§ 6. *Functions of the bark.*

The inner bark being connected with the under layer of vessels in the leaf, receives from them the sap after it has been changed by the action of the air and light, and transmits it downwards to the root.

The outer bark, especially in young twigs and in the stalks of the grasses, so closely resembles the leaves in its appearance, that we can have no difficulty in admitting that it must, not unfrequently, perform similar functions. In the Cactus, the Stapelia, and other plants which produce no true leaves, this outer bark seems to perform all the functions which in other vegetable tribes are specially assigned to the abundant foliage. During its descent through the inner bark, therefore, the sap must in very many cases undergo chemical changes, more or less analogous to those which usually take place in the leaf.

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* Sprengel *Chemie*, II., p. 347.

† See subsequent lecture, "*On the law of the decay of organic substances.*"

It is by means of the inner bark that the stems of trees, such as our forest and fruit trees, are enlarged by the deposition of annual layers of new wood. The woody fibre is formed or prepared in the leaf, and as the sap descends it is deposited beneath the inner surface of the inner bark. It thus happens that, as the sap descends, it is gradually deprived of the substances it held in solution when it left the leaf, and in consequence it becomes difficult to say how much of the change, which the sap is found to have undergone when it reaches the root, is due to chemical transformations produced during its descent, and how much to the deposition of the woody fibre and other matters it has parted with by the way.

Among other evidences of such changes really taking place during the descent of the sap, I may mention an observation of Meyen (*Jahresbericht*, 1839, p. 27), made in the course of his experiments on the re-production of the bark of trees. In these experiments he enclosed the naked wood in strong glass tubes, and in three cases out of eight the tubes were burst and shattered in pieces. This could only have arisen from the disengagement of gaseous substances, the result of decomposition. While, therefore, such gases as enter by the roots or are evolved in the vessels of the wood during the ascent of the sap, escape by the leaf along with those which are disengaged in the leaf itself, it is probable that those which are produced as the result of changes in the bark, descend with the downward sap, and are discharged by the root.*

In the bark of the root it is probable that still further changes take place—and of a kind which can only be effected during the absence of light. This is rendered probable by the fact that the bark of the root frequently contains substances which are not to be met with in any other part of the plant. Thus from the bark of the fresh root of the apple tree a substance named *phloridzine*, possessed of considerable medical virtues, may be readily extracted, though it does not exist in the bark either of the stem or of the branches.

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* Sprengel says that the stems, and twigs, and the stalks of the grasses, all absorb oxygen and give off carbonic acid.—*Chemie*, II., p. 341.

In fine, as the food which is introduced into the stomachs of animals, undergoes continual and successive chemical changes during its progress through the entire elementary canal—so, numerous phenomena indicate that the sap of plants is also subjected to unceasing transformations,—in the root and in the stem as well as in the leaves,—at one time in the dark, at another under the influence of the sun's rays,—exposed when in the leaf to the full action of the air, —and when in the root almost wholly secluded from its presence;—the new compounds produced in every instance being suited either to the nature of the plant or the wants and functions of that part of it in which each transformation takes place.

To some of these transformations it will be necessary to advert more particularly, when we come to consider the special changes by which those substances of which plants chiefly consist, are formed out of these compounds on which they chiefly live.

§ 7. *Circumstances by which the functions of the various parts of plants are modified.*

Plants grow more or less luxuriantly, and their several parts are more or less largely developed, in obedience to numerous and varied circumstances.

I. In regard to the special functions of the root, we have already seen that the access of atmospheric air is in some cases indispensable, while in others, by shooting vertically downwards, the roots appear to shun the approach of either air or light. It is obvious also that a certain degree of moisture in the soil, and a certain temperature, are necessary to the most healthy discharge of the functions of the root. In hot weather the plant droops, because the roots do not absorb water from the soil with sufficient rapidity. And though it is probable that, at every temperature above that of absolute freezing, the food contained in the soil is absorbed and transmitted more or less slowly to the stem, yet it is well known that a genial warmth in the soil stimulates the roots to increased activity. The practice of gardeners in applying *bottom* heat in the artificial climate of the green-house and conservatory is founded on this well known principle.

But the nature of the soil in which plants grow has also much influence on the way in which the functions of the root are discharged. As a general fact this also is well known, though the special qualities of the soil on which the greater or less activity of vegetation depends, are far from being generally understood. If the soil contain a sensible quantity of any substance which is noxious to plants, it is plain that their roots will be to a certain degree enfeebled, and their functions in consequence only imperfectly discharged. Or if the soil be deficient either in organic food, or in one or other of those inorganic substances which the plants necessarily require for the production of their several parts, the roots cannot perform their office with any degree of efficiency. Where the necessary materials are wanting the builder must cease to work. So in a soil which contains no silica, the grain of wheat may germinate, but the stalk cannot be produced in a natural or healthy state, since silica is indispensable to its healthy construction.

II. The ascent of the sap is modified chiefly by the season of the year, by the heat of the day, and by the genus and age of the plant or tree.

There seems reason to believe that the plant never sleeps, that even during the winter the circulation slowly proceeds, though the first genial sunshine of the early spring stimulates it to increased activity. The general increased temperature of the air does not produce this acceleration in so remarkable a manner as the direct rays of the sun. The sap will flow and circulate on the side of a tree on which the sunshine falls, while it remains sensibly stagnant on the other. This is shown by the cutting down similar trees at more and more advanced periods of the spring, and immersing their lower extremities in coloured solutions. The wood and bark on one side of the tree will be coloured, while on the other, both will remain unstained. If a similar difference in the comparative rapidity of the circulation on opposite sides of a trunk or branch be supposed to prevail more or less throughout the year, we can readily account for the annual layers of wood being often thicker on the one half of the circumference of the stem than on the other.

The sap is generally supposed to flow most rapidly during the spring, but if trees be cut down at different seasons, and immersed as above described, the coloured solution, according to Boucherie, reaches the leaves most rapidly in the autumn.*

The heat of the day, other circumstances being the same, materially affects, for the time, the rapidity of the circulation. The more rapidly watery and other vapours are exhaled from the leaves, the more quickly must the sap flow upwards to supply the waste. If on two successive days the loss by the leaves be, as in the experiment of Hales, above described, (p. 129,) as 2 to 3, the ascent of the sap must be accelerated or retarded in a similar proportion. Hence, every sensible variation in the temperature and moisture of the air, must also, to a certain extent, modify the flow of the sap; must cause a greater or less transport of that food which the earth supplies, to be carried to every part of the plant, and must thus sensibly affect the luxuriance and growth of the whole.

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* Boucherie makes a distinction, not hitherto insisted upon by physiologists, between the circulation on the surface of the tree by which the buds and young twigs are supported, and the interior circulation which is not perfect until a later period of the year. Hence in the spring, though the sap is flowing rapidly through the bark and the newest wood, coloured solutions will not penetrate the interior of the tree with any degree of rapidity. In autumn, on the other hand—when the fear of approaching winter has already descended upon the bark—the time of most active circulation has only arrived for the interior layers of the older wood. It is this season consequently that he finds most favourable for impregnating the trunks of trees with those solutions which are likely to preserve them from decay.—*Ann. de Chim. et de Phys.* lxxiv., p. 135.

But the persistance of the leaves is a generic character, which has considerable influence upon the circulation in the *evergreens.* In the pine and the holly, from which the leaves do not fall in the autumn, the sap ascends and descends during all the colder months,—at a slower rate, it is true, than in the hot days of summer, yet much more sensibly than in the oak and ash, which spread their naked arms through the wintery air. This is illustrated by the experiments of Boucherie, who has observed that in December and January the entire wood of resinous trees may be readily and thoroughly penetrated by the spontaneous ascent of saline and other solutions, into which their stems may be immersed.

III. From what has just been stated, it will appear that the mechanical functions of the stem are subject to precisely the same influences as the ascent of the sap. As the tree advances in age, the vessels of the interior will become more or less obliterated, and the general course of the sap will be gradually transferred to annual layers, more and more removed from the centre. It is this transference of the vital circulation to newer and more perfect vessels that enables the tree to grow and blossom and bear fruit through so long a life. In animals the vessels are gradually worn out by incessant action. None of them, through old age, are permitted to retire from the service of the body—and the whole system must stop when one of them is incapacitated for the further performance of its appointed duties.

In regard to the *chemical* functions of the stem, it is obvious that they are not assigned to the mere woody matter of the vessels and cells. They take place in these vessels, but the nature and extent of the chemical changes themselves must be dependant upon the quantity and kinds of matter which ascend or descend in the sap. The entire chemical functions of the plant, therefore, must be dependent upon and must be modified by the nature of the substances which the soil and the air respectively present to the roots and to the leaves.

IV. In describing the functions of the leaf, I have already had occasion to advert to the greater number of the circumstances by which the discharge of those functions is most materially affected. We have seen that the purposes served by the leaf are entirely different according as the sun is above or below the horizon; that the temperature and moisture of the air may indeed materially influence the rapidity with which its functions are discharged—but that the light of the sun actually determines their nature. Thus the leaf becomes green and oxygen is given off in the presence of the sun, while in his absence carbonic acid is disengaged, and the whole plant is blanched.

How necessary light is to the health of plants may be inferred from the eagerness with which they appear to long for it. How intensely does the sun-flower watch the daily course of the sun,—how do the countless blossoms nightly droop when he retires,—and the blanched plant strive to reach an open chink through which his light may reach it![*]

That the *warmth* of the sun has comparatively little to do with this specific action of his rays on the chemical functions of the leaf, is illustrated by some interesting experiments of Mr. Hunt, on the effect of rays of light of different colours on the growing plant. He sowed cress seed, and exposed different portions of the soil in which the seeds were germinating, to the action of the red, yellow, green, and blue rays, which were transmitted by equal thicknesses of solutions of these several colours. "After ten days, there was under the blue fluid, a crop of cress of as bright a green as any which grew in full light and far more abundant. The crop was scanty under the green fluid, and of a pale yellow, unhealthy colour. Under the yellow solution, only two or three plants appeared, but less pale than those under the green,—while beneath the red, a few more plants came up than under the yellow, though they also were of an unhealthy colour. The red and blue bottles being now mutually transferred, the crop formerly beneath the blue in a few days appeared blighted, while on the patch previously exposed to the red, some additional plants sprung up.*

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[*] A potato has been observed to grow up in quest of light from the bottom of a well twelve feet deep—and in a dark celler a shoot of 20 feet in length has been met with, the extremity of which had reached and rested at an open window. In the leaves of blanched vegetables peculiar chemical compounds are formed. Thus in the stalk of the potato a poisonous substance called *solanin* is produced, which disappears again when the stalk is exposed to the light and becomes green.

Besides the rays of heat and of light, the sun-beam contains what have been called chemical rays, not distinguishable by our senses, but capable of being recognised by the chemical effects they produce. These rays appear to differ in kind as the rays of different coloured light do. It is to the action of these chemical rays on the leaf, and especially to those which are associated with the blue light in the solar beam, that the chemical influence of the sun on the functions of the leaf is principally to be ascribed.

It cannot be doubted that the warmth and moisture of a tropical climate act as powerful stimulants—assistants it may be—to the leaf, in the absorption of carbonic acid from the air, and in that rapid appropriation (assimilation) of its carbon, by which the growth of the plant is hastened and promoted. But the bright sun, and especially the chemical influence of his beams, must be regarded as the main agent in the wonderful development of a tropical vegetation. Under this influence the growth by the leaves at the expense of the air must be materially increased, and the plant be rendered less dependent upon the root and the soil for the food on which it lives.†

V. The rapidity with which a plant grows has an important influence upon the share which the *bark* is permitted to take in the general nourishment of the whole. The green shoot performs in some degree the functions of the leaf. In vascular plants, therefore, which in a congenial climate may almost be seen to grow, the entire rind of a tall tree may more or less effectually absorb carbonic acid from the atmosphere, during the presence of the sun. The broad leaves of the palm tree, when fully developed, render the plant in a great degree independent of the soil for organic food—and the large amount of absorbing surface in the long green tender stalks of the grasses, and of their tropical analogues, must materially contribute to the same end. Hence the proportion of organic matter derived from the air, in any crop we reap, must always be the greater the more rapid its general vegetation has been.

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* *London and Edinburgh Journal of Science, February*, 1840.

Might not our cheap blue glass be used with advantage in glazing hot-houses, conservatories, &c.?

† The effect of continued sunshine may be often seen in our corn fields in May, when under the influence of propitious weather, the young plants are shooting rapidly up. When such a field is bounded by a lofty hedge running nearly north and south, the ridges nearest the hedge on either side will be in the shade for nearly one-half of the day, and will invariably appear of a paler green and less healthy colour. If the hedge be studded with occasional large trees, the spots on which the shadows of those trees rest will be indicated by distinct pale green patches stretching further into the field than the first, and sometimes even than the second ridges.

It is a fact familiarly known to all of you, that, besides those circumstances by which we can perceive the special functions of any one organ to be modified, there are many by which the entire economy of the plant is materially and simultaneously affected. On this fact the practice of agriculture is founded, and the various processes adopted by the practical farmer are only so many modes by which he hopes to influence and promote the growth of the whole plant, and the discharge of the functions of all its parts.

Though manures in the soil act immediately through the roots, they stimulate the growth of the entire plant; and though the application of a top-dressing may be supposed first to affect the leaf, yet the beneficial result of the experiment depends upon the influence which the dressing may exercise on every part of the vegetable tissue.

In connection with this part of the subject, therefore, I shall only further advert to a very remarkable fact mentioned by Sprengel, which seems, if correct, to be susceptible of important practical applications. He states that it has very frequently been observed in Holstein, that if, on an extent of level ground sown with corn, some fields be marled, and others left unmarled, the corn on the latter portions will grow *less luxuriantly* and will *yield a poorer* *crop than if the whole had been unmarled.* Hence he adds, if the occupier of the unmarled field would not have a succession of poor crops, he must marl *his* land also.*

Can it really be that nature thus rewards the diligent and the improver? Do the plants which grow on a soil in higher condition take from the air more than their due share of the carbonic acid or other vegetable food it may contain, and leave to the tenants of the poorer soil a less proportion than they might otherwise draw from it? How many interesting reflections does such a fact as this suggest! What new views does it disclose of the fostering care of the great Contriver—of his kind encouragement of every species of virtuous labour? Can it fail to read to us a new and special lesson on the benefits to be derived from the application of skill and knowledge to the cultivation of the soil?

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* Wenn nämlich auf einer Feldflur Stück um Stück gemergelt worden ist, so wachsen die Früchte auf den nicht gemergelten Feldern, auch wenn hier alle früheren verhältnisse ganz die-selben bleiben, nicht mehr so gut, als ehedem; wodurch die Besitzer jener Felder, wenn sie nicht fortwährend geringe Erndten haben wollen, genöthigt sind, gleichfalls zu mergeln. Aus dieser höchst vichtigen Erscheinung, die man *sehr häufig* in Holsteinschen bemerkt, &c.—Sprengel *Chemie für Landwirthschaft* I. p. 303.

LECTURE VI.

Substances of which plants chiefly consist—Woody fibre, Starch, Gum, Sugars—Their mutual relations and transformations—Gluten, Vegetable Albumen, Diastase—Acetic, Tartaric, Malic, Citric, and Oxalic Acids—General observations.

From what has been stated regarding the structure of plants, it will be understood in what way the food is introduced into their circulation. The next inquiry appears to be *how*—by what chemical changes—is the food, when introduced, converted into those substances of which plants chiefly consist. But in order that we may clearly understand this point, it is necessary that we know first the nature and chemical constitution of the substances which are most largely formed from the food in the interior of the plant. To this point, therefore, I must previously direct your attention.

If you were to collect all the varieties of plants which are within your reach—whether such as are cultivated and used for food—or such as grow more or less abundantly in a wild state—and were to extract their several juices, and to separate from each of these juices the chemical compounds it contains—you would gradually gather together so many different substances, all possessed of different properties, that you would scarcely be able to number them.

But if at the same time you compared the weight of each substance thus collected with that of the entire plant from which it is derived, you would find also that the quantity of many of them is comparatively so minute that only a very small portion of the vital energies of the plant can be expended in producing them,—that they may be entirely neglected in a general consideration of the great products of vegetation. Thus though quinine and morphine, the active ingredients in Peruvian bark and in opium, are most interesting substances, from their effect upon the human constitution, and their use in medicine, yet they form so small a fraction of the mass of the entire trees or plants from which they are extracted, that it would be idle to attempt to convey to you any notion of the way in which plants grow and are fed, by showing you how such substances as these are produced from the food on which plants live.

While, however, this examination would satisfy you that almost every species of plant produced in small quantity one or more substances peculiar to itself, you would observe, at the same time, that every plant yielded a certain quantity of two or three substances common to and produced by all, and in most cases constituting the greater portion of their bulk. Thus all trees and herbs produce wood or woody fibre, and of this substance you know that their chief bulk consists. Again, all the grains and roots you cultivate contain starch in large quantity, and the production of this starch is one of the great objects of the art of culture. The juices of trees, and of grasses, and of cultivated roots, contain sugar and gum, and sometimes in such quantity as to make their extraction a source of profit both to the grower and to the manufacturer. The flour of grain contains sugar also, and along with it two other substances, in small quantity, *gluten* and *vegetable albumen*, which are of much importance in reference to the nutritive qualities of the different varieties of flour. Sugar is also present in the juices of fruits, but it is there associated with various acid (sour) substances which disappear to a certain extent or change into sugar as the fruit ripens.

Of these few substances the great bulk of vegetables of all kinds consists. They constitute nearly the whole mass of those various crops which the art of culture studies to raise for the use of man and beast. To the study of these substances, therefore, I shall at present confine your attention, and if I shall afterwards be able to make you understand how these few compound bodies are produced in the interior of a plant from the food it takes up, I shall succeed in conveying to you as much information in regard to this most interesting branch of our subject as will be necessary to a general explanation not only of the natural growth and increase of plants, but of the nature and efficacy of those probable by the fact that the bark of the root frequently contains substances which are not to be met with in any other part of the plant. Thus from the bark of the fresh root of the apple tree a substance named *phloridzine*, possessed of considerable medical virtues, may be readily extracted, though it does not exist in the bark either of the stem or of the branches.

In fine, as the food which is introduced into the stomachs of animals, undergoes continual and successive chemical changes during its progress through the entire elementary canal—so, numerous phenomena indicate that the sap of plants is also subjected to unceasing transformations,—in the root and in the stem as well as in the leaves,—at one time in the dark, at another under the influence of the sun's rays,—exposed when in the leaf to the full action of the air,—and when in the root almost wholly secluded from its presence;—the new compounds produced in every instance being suited either to the nature of the plant or the wants and functions of that part of it in which each transformation takes place.

To some of these transformations it will be necessary to advert more particularly, when we come to consider the special changes by which those substances of which plants chiefly consist, are formed out of these compounds on which they chiefly live.

§ 7. *Circumstances by which the functions of the various parts of plants are modified.*

Plants grow more or less luxuriantly, and their several parts are more or less largely developed, in obedience to numerous and varied circumstances.

I. In regard to the special functions of the root, we have already seen that the access of atmospheric air is in some cases indispensable, while in others, by shooting vertically downwards, the roots appear to shun the approach of either air or light. It is obvious also that a certain degree of moisture in the soil, and a certain temperature, are necessary to the most healthy discharge of the functions of the root. In hot weather the plant droops, because the roots do not absorb water from the soil with sufficient rapidity. And though it is probable that, at every temperature above that of absolute freezing, the food contained in the soil is absorbed and transmitted more or less slowly to the stem, yet it is well known that a genial warmth in the soil stimulates the roots to increased activity. The practice of gardeners in applying *bottom* heat in the artificial climate of the green-house and conservatory is founded on this well known principle.

But the nature of the soil in which plants grow has also much influence on the way in which the functions of the root are discharged. As a general fact this also is well known, though the special qualities of the soil on which the greater or less activity of vegetation depends, are far from being generally understood. If the soil contain a sensible quantity of any substance which is noxious to plants, it is plain that their roots will be to a certain degree enfeebled, and their functions in consequence only imperfectly discharged. Or if the soil be deficient either in organic food, or in one or other of those inorganic substances which the plants necessarily require for the production of their several parts, the roots cannot perform their office with any degree of efficiency. Where the necessary materials are wanting the builder must cease to work. So in a soil which contains no silica, the grain of wheat may germinate, but the stalk cannot be produced in a natural or healthy state, since silica is indispensable to its healthy construction.

II. The ascent of the sap is modified chiefly by the season of the year, by the heat of the day, and by the genus and age of the plant or tree.

There seems reason to believe that the plant never sleeps, that even during the winter the circulation slowly proceeds, though the first genial sunshine of the early spring stimulates it to increased activity. The general increased temperature of the air does not produce this acceleration in so remarkable a manner as the direct rays of the sun. The sap will flow and circulate on the side of a tree on which the sunshine falls, while it remains sensibly stagnant on the other. This is shown by the cutting down similar trees at more and more advanced periods of the spring, and immers-

It is exceedingly difficult in any case to separate the cellular from the incrusting matter of wood, so as to obtain the means of determining by analysis the exact difference in their elementary constitution. Under the impression that in very light and porous substances he should obtain the cellular matter in a purer form, Payen analyzed the fibre of cotton—the pith of the elder, the cellular substance of the cucumber, of the mushroom, and of other fungi, the spongy matter which forms the extremities of the roots of plants, and various other similar substances, and in all these varieties he found the hydrogen and oxygen to exist in the proportions to form water. The mean of his analyses was very nearly as follows—which for the purpose of comparison I shall contrast with that of Dr. Prout:

of separating it from the cellular matter was by treating the finely rasped wood (of the oak and beech) with nitric acid, which dissolved out the incrusting matter and left the cellular matter behind. His second mode was to digest the wood with dilute sulphuric acid, by which the cellular matter was dissolved out, and the incrusting matter left. It is obvious, however, that no reliance whatever can be placed on the analyses of substances so treated, since they cannot fail to have undergone a chemical change by being exposed to the action of these strong acids. Further examination has satisfied Payen that the incrusting matter consists of at least *three* substances, of which one is soluble in water, alcohol, and ether, another in alcohol only, while the third is insoluble in any of these liquids. They are composed, according to this analyses, of

	Insoluble.	Soluble in alcohol only.	Soluble in water and alcohol.
Carbon . .	48	62·8	68·53
Hydrogen . .	6	5·9	7·04
Oxygen . .	46	31·3	24·43*
	100	100	100

It is impossible to say how far the substances analyzed by Payen are to be considered as pure, or as actually existing in the pores, or in the incrusting matter of the woody fibre, but it is obvious that the presence of a variable quantity of such substances will necessarily cause that excess of hydrogen, in the entire wood, which appears in the analysis of the ebony, walnut, oak, and beech woods, given in the text. That such an excess of hydrogen above what is necessary to form water with the oxygen, does exist in the wood of most trees in its natural state, is a fact to which it will be important to advert when we consider hereafter the chemical changes which the food undergoes in the interior of the plant.

[* Meyen's *Jahresbericht*, 1839, p. 10.]

	Woody fibre of box and willow—Dr. Prout.	Cellular matter of vascular plants—Payen.
Carbon	50·00	44·80
Hydrogen	5·55	6·20
Oxygen	44·45	49·0
	100	100[*]

In both these analyses the hydrogen is very nearly 8 times that of the oxygen. All these substances, therefore, may be represented by carbon and water, though the woody fibre of Dr. Prout contains 5 per cent. more carbon than the cellular matter of Payen.

If we calculate the number of equivalents of each element contained in these two varieties[†] of vegetable fibre composed as above exhibited, we find in the one 12 of carbon, 8 of hydrogen, and 8 of oxygen; in the other, 12 of carbon, 10 of hydrogen, and 10 of oxygen. They may, therefore, be conveniently represented by the following formulæ:

WOODY FIBRE . . . . . by C^{12} H^{8} C^{8}
CELLULAR FIBRE . . . . by C^{12} H^{10} C^{10}

It is not unlikely that both of these forms of matter may exist, as well in the perfect wood of trees as in the less consolidated pith of the elder, or in the fibres of cotton—and that they may occur intermingled also in varying proportions with other substances, containing hydrogen in excess.[‡]

I have spoken of these varieties of woody fibre as constituting a large portion of the entire mass of vegetable matter

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[*] Meyen's *Jahresbericht*, 1839, p. 10.

[†] This is done very simply by dividing the carbon by 6, and the oxygen by 8 (see page 42), thus—

Carbon . . .	50 ÷ 6 = 8·33	which numbers are to each other as	12
Hydrogen . .	5·55 = 5·55		8
Oxygen . . .	44·45 ÷ 8 = 5·55		8

[‡] The existence of a variety of cellular fibre identical in constitution with common starch, as this of Payen is, (see subsequent section, p. 155) was previously rendered probable by the observations of Dr. Schleiden, that the embryo of the *Schotia latifolia*, consisting of pores and vessels, the sides of which exhibit distinct concentric layers, is entirely soluble in water, with the exception of the outer rind; and that its solution becomes blue on the addition of iodine. It would appear as if the cellular substances were in this case wholly composed of starch. (*Poggendorf's Annalen*, xliii., p. 398.) It may, however, be in such a state of tenuity in

produced during the growth of plants. That such is the case in the more gigantic vegetable productions, of which the great forests consists, is sufficiently evident, and so far the general statement is easily seen to be correct. It is also true of the dried stalks of the grasses and of the corn-growing plants, of which it forms nearly one-half the weight,—but in roots and in some plants which are raised for food, the quantity of woody fibre, especially in the earlier stages of their growth, is comparatively small.* Thus in the beet root it forms only 3 per cent. of the whole weight when taken from the ground. If suffered to remain in the soil till it be-

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tion embryo of this plant, as to be easily changed into starch by the action of hot water; and it is still by no means certain that the cellular fibre analyzed by Payen may not also have undergone a change by the treatment to which it was previously subjected. I am unable, however, to speak decidedly on this subject, as I have not seen the details of M. Payen's several papers. (See subsequent section, *on the mutual transformations of woody fibre, starch, gum, and sugar*, p. 163.)

* The following table shows the per centage of woody fibre contained in some common plants in the green state, and when dried in the air, and at 212°:

			IN THE GREEN STATE.	
	Dried in the air. per cent.	Dried at 212° per cent.	Woody fibre. per cent.	Water. per cent.
Barley straw, ripe	50	—	—	—
Oat straw, do.	—	47	—	—
Maize straw, do.	24	—	—	—
Stalks of the field pea . . .	—	—	10¼	80
Field bean straw, ...	51	—	—	—
White turnip, ...	—	—	3	92
Common beet (beta vulgaris) .	—	—	3	86
Young twigs of common furze .	—	—	24	50
Rape straw, ripe	—	55	12¼	77
Tare straw, do.	37	—	—	—
Vetch plant (v. sativa) . .	42	—	10½	77½
Do. (v. cracca) in flower .	—	—	5½	68
Do. (v. narbonensis) do. .	—	—	11½	80
White lupin, in flower, . . .	—	—	7	86
Lucerne, in flower, ...	—	—	9	73
Rye grass, do.	—	—	11	63
Red clover, do.	—	—	7	79
White clover, do.	—	—	4½	81
Trefoil (medium) do. . . .	—	—	8½	73
Sainfoin (esparsette) . . .	—	—	7	76
Trefoil (agrarium) in flower . .	—	—	12	68
Do. (rubens) do . .	—	—	15	60

comes old, or if the growth be very slow, the beet becomes more woody, as many other roots do, and the quantity of ligneous fibre increases.

§ 2. *Starch—its constitution and properties.*

Next to woody fibre, starch is probably the most abundant product of vegetation. To the agriculturist it is a substance of much more interest and importance than the woody or cellular fibre, from the value it possesses as one of the staple ingredients in the food of man and animals—and from its forming a large portion of the weight of the various grains and roots which are the principal objects of the art of culture.

1°. When the flour of wheat, barley, oats, Indian corn, &c., is mixed up into a dough with water, and this dough washed on a linen cloth with pure water, a milky liquid passes through, from which, when set aside, a white powder gradually falls. This white powder is the *starch* of wheaten or other flour.

2°. When the pith of the sago palm is washed, in a similar manner, with water upon a fine sieve, a white powder is deposited by the milky liquid which passes through. This, when collected, forced through a metal sieve to granulate (or corn) it, and dried by agitation over the fire, is the *sago* of commerce.

3°. When the raw potato is peeled and grated on a fine grater, and the pulp thus produced well washed with water, *dotato starch* is obtained in the form of a fine white powder, consisting of rounded, glossy and shining particles.

4°. When the roots of the *Maranta Arundinacea* of the West India Islands are grated and washed like the potato, they yield the *arrow root* of commerce. From the root of the Manioc, the *cassava* is procured by a similar process, and this, when dried by agitation on a hot plate, is the *tapioca* of the shops. By this method of drying, both sago and tapioca undergo a partial change, which will be explained in a subsequent section (see p. 165.)

The substances to which these several names are given are, when pure, similar in their properties, and identical in their chemical constitution. They are all colourless, tasteless, without smell, when dry and in a dry place may be kept for any length of time without undergoing alteration, are insoluble in cold water or alcohol, dissolve readily in boiling water, giving a solution which gelatinizes (becomes a jelly) on cooling—and in a cold solution of iodine* they all become blue.

When dried at 212°, they consist, according to Dr. Prout, with whose analysis those of other chemists agree, of

Carbon . . .	44·0 per cent., or	12 atoms.
Hydrogen . . .	6·2 per cent., or	10 atoms.
Oxygen . . .	49·8 per cent., or	10 atoms.
	100	

Starch, therefore, may be represented by the formula $C^{12} H^{10} O^{10}$, which is identical with that deduced in the preceding section for the *cellular fibre* of Payen. Both substances, therefore, contain the same elements (carbon, hydrogen and oxygen,) united in the same proportions, and in both, as well as in the common fibre of wood, the hydrogen and oxygen exist in the proportion to form water.

That starch constitutes a large portion of the weight of grains and roots, usually grown for food, will appear from the following table, which exhibits the quantity present in 100 lbs. of each substance named:

	Starch per cent.
Wheat flour	39 to 77
Rye do.	50 to 61
Barley do.	67 to 70
Oatmeal	70 to 80
Rice flour	84 to 85
Maize do	77 to 80
Buck wheat	52
Pea and Bean meal	42 to 43
Potatoes, containing 73 to 78 of water, .	13 to 15

It thus exists most largely in the seeds of plants, and in some roots. It is frequently deposited, however, among the woody fibre of certain trees, as in that of the willow, and in the inner bark of others, as in those of the beech and the pine.* Hence the readiness with which a branch of the willow takes root and sprouts, and hence also the occasional use of the inner bark of trees for food, especially in northern countries, and in times of scarcity. In some roots which abound in sugar, as in those of the beet, the turnip, and the carrot, only 2 or 3 per cent. of starch can be detected.

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* Iodine is a solid substance, of a lead-grey colour, possessed of a peculiar powerful odour, and forming when heated a beautiful violet vapour. It exists in small quantity in sea water, and in some marine plants. Its solution in water readily shows the presence of starch, by the blue colour it imparts to it.

§ 3. *Gum—its constitution and properties.*

The variety of gum with which we are most familiar is *gum arabic*, or *senegal*, the produce of various species of *acacia*, which grow in the warmer regions of Asia, Africa, and America. It exudes from the twigs and stems of these trees, and collects in rounded more or less transparent drops or tears. It is also produced in smaller quantities in many of our fruit trees, as the apple, the plum, and the cherry; it is present in some herbaceous plants, as in the althae and malva officinalis (common and marsh mallow); and it exists in lint, rape, and many other seeds. When treated with boiling water these plants and seeds give mucilaginous solutions.

Many varieties of gum occur in nature, but they are all characterized by being insoluble in alcohol, by dissolving or becoming gelatinous in hot or cold water, and by giving *mucilaginous*—viscid and glutinous—solutions, which may be employed as a paste.

Three distinct species of gum have been recognised by chemists.

1°. *Arabin*—of which gum arabic and gum senegal almost entirely consist. It is *readily soluble in cold water*, giving a viscid solution, usually known by the name of the *mucilage* of gum arabic.

2°. *Cerasin*—which exists in the gum of the cherry-tree. It is *insoluble in cold water*, but *dissolves readily in boiling*

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* Its presence is readily detected in such wood by a drop of the solution of iodine—which gives a permanent blue to starch, but to the woody fibre only a brownish stain.

water. When thus dissolved it may be dried without losing its solubility, and is therefore by boiling supposed to be changed into arabin.

3°. *Bassorin*—existing in what is called *bassora gum*—and forming a large portion of gum tragacanth.* It *swells and becomes gelatinous in cold water, but does not dissolve in water either cold or hot.*

By these characters, the three kinds of gum are not only readily distinguished, but may be easily separated from each other. Thus if a native gum or an artificial mixture contain all the three, simple steeping in and subsequent washing with *cold* water, will separate the *arabin*—boiling water will then take up the *cerasin*, and the *bassorin* will remain behind.

These different kinds of gum all possess the same chemical constitution.

According to the analyses of Mulder, they consist of

Carbon . . .	45·10 per cent., or	12 atoms.
Hydrogen . . .	6·10 per cent., or	10 atoms.
Oxygon . . .	48·80† per cent., or	10 atoms.
	100	

In these analyses, as in those of starch and woody fibre, we see that the per centage of oxygen is equal to that of the hydrogen multiplied by 8, and consequently that these two elements are, as already stated, in the proportion to form water. But we see also that the carbon is in the proportion of 12 atoms or equivalents to 10 of each of the other constituents, and therefore gum may be represented by $C^{12} H^{10} O^{10}$—a formula which is identical with that already given for starch and cellular fibre.

It appears, therefore, that not only may *gum*, *starch*, and *cellular fibre* be represented by carbon and water, but that they *all consist of carbon and the elements of water, united together in the same proportions.*

Gum not only exists in many seeds, and exudes as a natural product from the stems and twigs of many trees, but is also contained in the juices of many other trees, from which it is not known to exude; and in the sap of most plants it may be detected in greater or less quantity. It may be considered, indeed, as one of those substances which are produced most largely and most abundantly in the vegetable kingdom, since, as will hereafter appear, it is one of those forms of combination through which organic matter passes in the interesting series of changes it undergoes during the development and growth of the plant.

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* This gum exists along with starch in the roots of the various species of *orchis*, especially of those which are used for making *salep* (Meyen).

† Berzelius *Årsberättelse*, 1839, p. 443.

§ 4. *Of Sugar—its varieties and chemical constitution.*

1°. *Cane Sugar.*—Sugar, identical in constitution and properties with that obtained from the sugar-cane, and generally known by the name of *cane*-sugar, exists in the juices of many trees, plants, and roots. In the United States of North America the juice of the maple tree is extensively collected in spring, and when boiled down yields an abundant supply of sugar. In the Caucasus that of the walnut is extracted for the same purpose. The juice of the birch also contains sugar, and it may be obtained, in lesser quantity, from the sap of many other trees. In the juice of the turnip, carrot, and beet, it is also present, and in France and Germany the latter root is extensively cultivated for the manufacture of beet sugar. In the unripe grains of corn, at the base of the flowers of many grasses and clovers when in blossom, and even in many small roots, as in that of the quicken or couch-grass (triticum repens), the presence of sugar may likewise be readily detected.

Sugar is principally distinguished by its agreeable sweet taste. When pure, it is colourless and free from smell. It dissolves readily in alcohol and in large quantity in water. The solution in water, when much sugar is present, has an oily consistence, and is known by the name of *syrup.* From this syrup the sugar gradually deposits itself in the form of crystals of *sugar candy.* If the syrup be boiled on too hot a fire, it chars slightly, becomes discoloured, and a quantity of *molasses* is formed. Pure *cane*-sugar, free from water, consists of

Carbon	44·92 per cent.,	or 12 atoms.
Hydrogen . . .	6·11 "	or 10 "
Oxygen	48·97 "	or 10 "
	100	

If we compare these numbers with those given for starch and gum in the preceding sections, we see that they are almost identical—so that cane-sugar also contains oxygen and hydrogen in the proportions to form water, and may likewise be represented by the formula $C^{12} H^{10} O^{10}$.

2°. *Grape-sugar.*—In the juice of the grape a peculiar species of sugar exists, which, in the dried raisin, presents itself in the form of little rounded grains. The same kind of sugar gives their sweetness to the gooseberry, the currant, the apple, pear, plum, apricot, and most other fruits. It is also the sweet substance of the chesnut, of the brewers' wort, and of all fermented liquors, and it is the solid sugar which floats in rounded grains in liquid honey, and which increases in apparent quantity as the honey, by keeping, becomes more and more solid.

Grape-sugar has nearly all the sensible characters of cane-sugar, with the exception of being less soluble in water and also less sweet,—2 parts of the latter imparting an equal sweetness wih 5 of the former.

In chemical constitution they differ considerably. Thus grape-sugar dried at 250° F., consists of

Carbon	40·47 per cent.,	or 12 atoms.
Hydrogen . . .	6·59 "	or 12 "
Oxygen	52·94 "	or 12 "
	100	

The oxygen here is still eight times greater than the hydrogen, and, therefore, in this variety of sugar also, these elements exists in the proportions to form water. But for every 12 equivalents of carbon dry grape sugar contains 12 of hydrogen and 12 of oxygen. It is consequently represented by $C^{12} H^{12} O^{12}$, and contains the elements of two atoms of water ($H^2 O^2$) more than cane-sugar.*

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* Solutions of cane and grape sugar are readily distinguished from each other by the following chemical characters:—1. If the solution be heated and a few drops of sulphuric acid then added, cane-sugar will be

3°. *Manna sugar, sugar of liquorice, &c.*—Besides the cane and grape sugars which occur in large quantity in the juices of plants, there are other varieties which occur less abundantly, and are therefore of less interest in the study of the general vegetation of the globe. Among these is *manna*, which partly exudes and is partly obtained by incisions from certain species of the *ash* tree which grow in the warmer countries of Southern Europe (Sicily and Italy), and in Syria and Arabia. It also exists, it is said, in the juice of the larch tree of common celery, and of certain trees which are met with in New South Wales. Liquorice root also contains a species of *black* sugar, which is known in this country under the names of Spanish and Italian juice, from the countries where it is grown. In the mushroom and other *fungi* a colourless variety, apparently peculiar, has also been met with,—and milk owes its sweetness to a species of sugar formed in the interior of the animal along with the other substances which the milk contains.

These several kinds of sugar differ more or less, not only in sensible and chemical properties, but also in chemical constitution from the more abundant cane and grape sugars—but they form too small a part of the general products of vegetation, and are of two little consequence in practical agriculture to render it necessary to do more than thus shortly advert to their existence.*

§ 5. *Mutual relations of woody fibre, starch, gum, and sugar.*

It may be interesting now to consider for a moment the mutual relations of the several substances, woody fibre, starch, gum, and sugar—above described—which occur so largely in the vegetable kingdom, and are serviceable to man for so many different purposes. These relations will be

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decomposed, blackened, and made to fall as a black or brown powder—while a solution of grape sugar will at the most be only slightly discoloured. 2. If instead of sulphuric acid, caustic potash be employed, the cane sugar will be unchanged, while the grape sugar will be blackened and thrown down.

* For a list of plants from which sugar has been extracted, see Thomson's *Organic Chemistry* (1838), p. 647.

It is exceedingly difficult in any case to separate the cellular from the incrusting matter of wood, so as to obtain the means of determining by analysis the exact difference in their elementary constitution. Under the impression that in very light and porous substances he should obtain the cellular matter in a purer form, Payen analyzed the fibre of cotton—the pith of the elder, the cellular substance of the cucumber, of the mushroom, and of other fungi, the spongy matter which forms the extremities of the roots of plants, and various other similar substances, and in all these varieties he found the hydrogen and oxygen to exist in the proportions to form water. The mean of his analyses was very nearly as follows—which for the purpose of comparison I shall contrast with that of Dr. Prout:

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of separating it from the cellular matter was by treating the finely rasped wood (of the oak and beech) with nitric acid, which dissolved out the incrusting matter and left the cellular matter behind. His second mode was to digest the wood with dilute sulphuric acid, by which the cellular matter was dissolved out, and the incrusting matter left. It is obvious, however, that no reliance whatever can be placed on the analyses of substances so treated, since they cannot fail to have undergone a chemical change by being exposed to the action of these strong acids. Further examination has satisfied Payen that the incrusting matter consists of at least *three* substances, of which one is soluble in water, alcohol, and ether, another in alcohol only, while the third is insoluble in any of these liquids. They are composed, according to this analyses, of

	Insoluble.	Soluble in alcohol only.	Soluble in water and alcohol.
Carbon . .	43	62·8	68·53
Hydrogen . .	6	5·9	7·04
Oxygen . .	46·	31·3	24·43*
	100	100	100

It is impossible to say how far the substances analyzed by Payen are to be considered as pure, or as actually existing in the pores, or in the incrusting matter of the woody fibre, but it is obvious that the presence of a variable quantity of such substances will necessarily cause that excess of hydrogen, in the entire wood, which appears in the analysis of the ebony, walnut, oak, and beech woods, given in the text. That such an excess of hydrogen above what is necessary to form water with the oxygen, does exist in the wood of most trees in its natural state, is a fact to which it will be important to advert when we consider hereafter the chemical changes which the food undergoes in the interior of the plant.

[* Meyen's *Jahresbericht*, 1839, p. 10.]

	Woody fibre of box and willow—Dr. Prout.	Cellular matter of vascular plants—Payen.
Carbon	50·00	44·80
Hydrogen	5·55	6·20
Oxygen	44·45	49·0
	100	100*

In both these analyses the hydrogen is very nearly 8 times that of the oxygen. All these substances, therefore, may be represented by carbon and water, though the woody fibre of Dr. Prout contains 5 per cent. more carbon than the cellular matter of Payen.

If we calculate the number of equivalents of each element contained in these two varieties† of vegetable fibre composed as above exhibited, we find in the one 12 of carbon, 8 of hydrogen, and 8 of oxygen; in the other, 12 of carbon, 10 of hydrogen, and 10 of oxygen. They may, therefore, be conveniently represented by the following formulæ:

Woody Fibre . . . . . by $C^{12}\,H^{8}\,C^{8}$
Cellular Fibre . . : . by $C^{12}\,H^{10}\,C^{10}$

It is not unlikely that both of these forms of matter may exist, as well in the perfect wood of trees as in the less consolidated pith of the elder, or in the fibres of cotton—and that they may occur intermingled also in varying proportions with other substances, containing hydrogen in excess.‡

I have spoken of these varieties of woody fibre as constituting a large portion of the entire mass of vegetable matter

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* Meyen's *Jahresbericht*, 1839, p. 10.

† This is done very simply by dividing the carbon by 6, and the oxygen by 8 (see page 42), thus—

Carbon . . .	50 ÷ 6 = 8·33	which numbers are to each other as	12
Hydrogen . .	5·55 = 5·55		8
Oxygen . . .	44·45 ÷ 8 = 5·55		8

‡ The existence of a variety of cellular fibre identical in constitution with common starch, as this of Payen is, (see subsequent section, p. 155) was previously rendered probable by the observations of Dr. Schleiden, that the embryo of the *Schotia latifolia*, consisting of pores and vessels, the sides of which exhibit distinct concentric layers, is entirely soluble in water, with the exception of the outer rind; and that its solution becomes blue on the addition of iodine. It would appear as if the cellular substances were in this case wholly composed of starch. (*Poggendorf's Annalen*, xliii., p. 398.) It may, however, be in such a state of tenuity in

best seen on comparing the formulæ by which they are respectively represented. Thus—

Woody Fibre	(lignin) is represented	by	$C^{12} H^{8} O^{8}$
Cellular Fibre	(according to Payne)	by	$C^{12} H^{10} O^{10}$
Starch	(dried at 212° F.)	by	$C^{12} H^{10} O^{10}$
Gum	(any of the 3 varieties)	by	$C^{12} H^{10} O^{10}$
Cane Sugar	(free from water)	by	$C^{12} H^{10} O^{10}$ *
Grape Sugar	(dried at 130° F.)	by	$C^{12} H^{12} O^{12}$ †

In these formulæ we observe—

1°. That the equivalents of the oxygen are equal to those of the hydrogen in *all* the formulæ, and, therefore, that all these substances may be *supposed* to consist of carbon and water.

2°. The formulæ for cellular fibre, starch, gum, and cane-sugar are identical. *They consist of the same elements united together in the same proportions.*

This is one of those facts which not only appear very remarkable to the unlearned, but are scarcely capable of being clearly comprehended and explained, even by those who have most profoundly studied this branch of natural science. Starch and sugar—how different their properties! how unlike their uses! how unequal their importance to the human race! yet they consist of the same weights of the same substances, differently conjoined. The skilful architect can put together the same proportions of the same stone and cement—and the painter can combine the same colours so as to produce a thousand varied impressions on the sense of sight. In the hand of Deity matter is infinitely more plastic. At His bidding the same particles can unite in the same quantity so as to produce the most unlike impressions—and on *all* our senses at once.

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* For a list of plants from which sugar has been extracted, see Thomson's *Organic Chemistry* (1838), p. 647.

† Crystallized cane-sugar (sugar candy) loses 5.3 per cent. of water in favourable circumstances. This is equal to one equivalent (H O), so that if dry sugar be $C^{12} H^{10} O^{10}$, crystallized sugar is $C^{12} H^{11} O^{11}$—or $C^{12} H^{10} O^{10} + H O$, since there is no doubt that this one equivalent of the hydrogen and oxygen exist in crystallized sugar in the state of water. In like manner, crystallized honey or grape-sugar—as it occurs in honey or in the dried grape—loses 9 per cent. of water when heated to 250° F. This is equal to two equivalents (2 H O), so that crystallized grape-sugar is represented by $C^{12} H^{14} O^{14}$ or $C^{12} H^{12} O^{12} + 2 H O$.

3°. A knowledge of the above close relations in composition, among a class of substances occurring so abundantly in the vegetable kingdom, imparts a degree of simplicity to our ideas of this otherwise complicated subject. It does not appear so mysterious that we should have woody fibre, and starch, and gum, and sugar, occurring together in variable quantities, when we know that they are all made up of the same materials, in the same or nearly the same proportions —or that one of these should occasionally disappear from a plant, to be replaced in whole or in part by another.

A further question, however, arises in our minds. We naturally ask,—does nature, in thus removing one of these compounds, and supplying its place by another, actually form from its elements the new substance introduced, or does she produce it by a mere change or transformation of those previously existing. A satisfactory reply to this question may be derived from the facts detailed in the following section.

§ 6. *Mutual transformations of woody fibre, starch, gum, and sugar.*

I.—WOODY FIBRE.

Action of heat.—If wood be reduced to the state of fine saw-dust, be then boiled in water to separate every thing soluble, afterwards dried by a gentle heat, and then heated several times in a baker's oven, it will become hard and crisp, and may be ground in the mill into a fine meal. The powder thus obtained is slightly yellow in colour, but has a taste and smell similar to the flour of wheat; it ferments when made into a paste with yeast or leaven, and when baked gives a light homogeneous bread. Boiled with water, it yields a stiff tremulous jelly, like that from starch (Autenrieth.)* By the agency of heat, therefore, it appears that the *woody fibre may be changed into starch.*

2°. *Action of sulphuric acid.*—If to three parts of the sulphuric acid of the shops (oil of vitriol) one part of water be added, and a portion of delicate woody fibre be immersed in it for half a minute, and the whole then rubbed in a mortar with a few drops of a solution of iodine—the woody fibre will assume a *blue colour*, showing that it is in part at least *changed into starch** (Schleiden).

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* Schübler, *Agricultur Chemie*, i., p. 224.

Again, if three-parts of fine saw-dust or of fragments of old linen be rubbed in a mortar with four of the sulphuric acid of the shops added by degrees—it will, in a quarter of an hour, be rendered completely soluble in water. If the solution in water be freed from acid by chalk, and then evaporated, a substance resembling gum arabic is obtained (Braconnot). According to Schleiden, the fibre may be seen under the microscope gradually to change from without inwards, first into starch and then into gum.

Further, if this gum be digested with a second portion of sulphuric acid diluted with 8 or 10 times its weight of water, it will be gradually converted into *grape-sugar;* or the fibre of wood or linen may be changed directly into sugar by the prolonged action of dilute sulphuric acid.

3°. *Action of Potash.*—If saw-dust be mixed with from two to eight times its weight of hydrate† of potash and as much water, and boiled till a crust forms on the surface, and if dilute sulphuric acid be then added till the whole is slightly sour, the undestroyed woody fibre will give an instantaneous deep blue on the addition of iodine, showing that starch has been formed.

Woody fibre, therefore, may be changed into starch, either by the unaided action of heat, by that of sulphuric acid, or by boiling with caustic potash,—and the starch thus produced may be further transformed, first into gum and then into grape-sugar, by the prolonged action of dilute sulphuric acid, assisted by a moderate heat.

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* It will be recollected that starch is characterized by giving a blue colour with a solution of iodine (see p. 156).

The simplest way of trying this experiment is, to take a quantity of clean cotton—to wet it with water, squeezing out again as much as possible—then to spread it out upon a flat dish and moisten it quickly and thoroughly with the acid diluted as above. After half a minute, add the solution of iodine, stir quickly with a glass rod, and immediately add water, when the blue compound of iodine and starch will speedily deposit itself.—(Schleiden *Pog. Annal.* xliii., p. 396).

† Hydrate of potash is the caustic substance which is obtained by boiling common pearl-ash with quick-lime.

II.—STARCH.

1°. *Action of heat.*—When flour, potato, or arrow-root starch is spread out upon a tray, then introduced into an oven and gradually heated to a temperature not exceeding 300° F., it slowly changes, acquires a yellow or brownish tint according to the temperature employed, and becomes entirely soluble in cold water. *It is changed into gum.* Under the names of starch-gum, or British-gum, this substance is largely manufactured in this country, and is successively substituted for gum arabic by the calico printers in thickening many of their colours.*

The gum thus prepared not unfrequently also possesses a sweet taste, from the further change of a portion of the gum into sugar.

2°. *Action of water.*—When starch is dissolved in boiling water, and is then allowed to stand in the cold either in a close vessel or exposed to the air, it gradually changes into gum or sugar. The process however, is slow, and months must elapse before the whole of the starch is thus spontaneously transformed in the presence of water (De Saussure). It takes place more rapidly when starch and water are boiled together for a length of time.

3°. *Action of sulphuric acid.*—From what has been already stated in regard to the action of this acid on woody fibre it will readily be supposed that native starch, of any variety, is likely to undergo transformation when subjected to its influence.

In reality, if 50 parts of starch, 12 of sulphuric acid, and 139 of water be taken, and if the starch be thoroughly moistened with a portion of the water, and then poured into the mixture of the acid with the remainder of the water, and heated to 190° F., the starch will be entirely converted into gum. By further and more prolonged heating this gum is changed into grape-sugar The gum or sugar may be obtained in a separate state by adding to the solution either chalk or lime, which will combine with and carry down the acid.* One hundred pounds of starch treated in this way will yield from 105 to 122 lbs. of dry grape-sugar.

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* During the baking of bread this conversion of starch into gum takes place to a considerable extent. Thus Vogel found that flour which contained no gum gave, when baked, a bread of which 18 per cent., or nearly one-fifth of the whole weight, consisted of gum. Thus one of the effects of baking is to render the flour-starch more soluble, and therefore (?) more easily digestible.

The rapidity with which this transformation takes place depends partly upon the temperature and partly upon the proportion of acid employed. Thus 100 lbs. of starch mixed with 600 of water and 10 of sulphuric acid, will be converted into grape-sugar by boiling for *seven* hours. If by increasing the pressure the temperature be raised to 250° F., the transformation will be effected in a *few minutes*. With only one pound of acid and the same quantity of starch and water, the change will be effected in *three* hours by a temperature of 230° F. This mode of converting potato starch into grape sugar is said to be extensively practised in France, for the purpose of subsequently fermenting the sugar and converting it into *brandy*.

III.—GUM.

Action of sulphuric acid.—If powdered gum arabic be rubbed in a mortar with the sulphuric acid of the shops, a brownish solution is obtained, which, when diluted with water and treated with chalk, yields a gummy substance similar to that obtained in the same way from starch and woody fibre. Prolonged digestion with diluted acid converts a portion of this gum into sugar.†

IV.—CANE SUGAR.

1°. *Action of heat.*—When crystallized cane sugar is heated to 320° F. it melts, and if the temperature be raised to 360° F. it gives off two atoms of water and is changed into *caramel.* This caramel is an uncrystallisable sugar, which is generally present in artificial syrups, and is often of a brownish colour. It contains the elements of an atom of water less than cane-sugar, and is represented by $C^{12} H^{9} O^{9}$. It is not known to occur in the natural juices of plants.

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* It forms *gypsum* with it (sulphate of lime), which is a compound of lime and sulphuric acid.

† Berzelius, *Traité de Chemie* (1831), v., p. 217.

2°. *Action of sulphuric acid.*—When cane-sugar is digested with dilute sulphuric acid, aided by a gentle heat, it is rapidly converted into grape-sugar. The acid of grapes (tartaric acid) and many other vegetable acids produce a similar change.

It is obvious that this conversion of cane into grape sugar can only take place in the presence of water, inasmuch, as has already been shown (p. 161), grape-sugar contains the elements of two atoms of water more than cane-sugar, or

$$\overset{\text{Cane sugar.}}{C^{12} H^{10} O^{10}} + \overset{\text{Water.}}{2HO} = \overset{\text{Dry grape sugar}}{C^{12} H^{12} O^{12}}.$$

We may revert now to the question with which we concluded the preceding section. Since these different substances are so closely allied in chemical constitution, and occur so often in connection with each other in the vegetable kingdom, does nature, when her purposes demand the change, actually transform them, the one into the other, in the interior of the plant? The answer may now be safely given, that she certainly does. What we can so readily perform by our rude art may be still more easily effected in the living vegetable. That which is starch or gum in one part of the plant, may become cane or grape sugar in another, and woody fibre in a third. Thus by re-arranging the same kind and quantity of the several elements, may the various and unlike forms of matter which constitute the main products of vegetation be readily produced.

Still the facility is only apparent. We can assure ourselves of the fact of such conversions, because we can at will induce them. But who operates upon these substances in the interior of the plant? Whose mind and will directs these changes—prescribing when, where, and in what order they shall take place? How much depends upon the refined and little understood mechanism of the vegetable structure—how much on the living principle itself! What is this living principle—how can *it* direct![*]

§ 7. *Of the fermentation of starch and sugar—and of the relative circumstances under which cane and grape sugars generally occur in nature.*

It will be of use to us, in connection with the above transformations, to advert to the property possessed by starch and nearly all the known varieties of sugar of entering into fermentation under favourable circumstances. When flour is made into a paste with leaven or yest it begins to rise and ferment,—sooner or later, according to the kind of flour and the quantity of ferment added. When to a decoction of malt or to a solution of starch or of cane or grape sugar in water a portion of yest is added, fermentation is speedily induced; and if not arrested by unfavourable circumstances it will continue until the whole of the starch or sugar disappears.

In all these cases it is grape-sugar alone that undergoes fermentation.[†] The starch of the moist dough or of the solution is partially transformed into grape-sugar before fermentation commences. Such is the case also with the decoction of malt and with cane sugar. The fermentation commences soon after the first portion of grape-sugar is formed, and proceeds more or less rapidly according as this transformation is more or less speedily effected. Hence, in the art of brewing, the necessity of cautiously regulating the temperature by which this change of the starch and sugar is promoted and hastened.

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[*] "Canst thou by searching find out God—Canst thou find out the Almighty unto perfection?"

[†] Rose, *Poggen. Annal.*, lii. p. 297.

The fermentation itself is the result not of a mere *transformation* of one form of matter into another having the same elementary constitution, but of a *decomposition* of one substance into two others unlike itself either in properties or in chemical composition. The grape sugar is resolved into alcohol (spirits of wine), which remains in the liquid, and into carbonic acid, which escapes in the form of gas and causes the fermentation. Thus alcohol being represented by $C^4 H^6 O^2$, and carbonic acid by CO^2,

$$\begin{array}{lll} \text{2 of alcohol} & = & C^8 H^{12} O^4 \text{ and} \\ \text{4 of carbonic acid} & = & C^4 \quad O^8 \text{ make up} \\ \hline \text{1 of grape sugar} & = & C^{12} H^{12} O^{12} \end{array}$$

It is an interesting fact that the cane and grape sugars occur in nature in circumstances which are entirely consistent with the statement in the preceding section, regarding the action of acids on the former variety of this natural product. Fruits contain grape sugar, which increases in quantity as they ripen or become less sour. In the sugar cane, the beet root, and the maple and birch trees, cane-sugar exists, but in their juices no acid is associated with the sugar. On the contrary, ammonia is known to be present in most of them along with the cane-sugar. Hence it is inferred, that as in our hands and in our experiments cane-sugar is changed by the agency of acids into grape-sugar, and with remarkable ease by that acid which exists in the ripe grape, so it is in the interior of plants. Where sugar occurs in connection with an acid in the juice of a plant, it is grape sugar in whole or in great part, because in the presence of an acid body cane-sugar cannot permanently exist, but is gradually transformed into the sugar of grapes. It thus appears also why fruits so readily enter into fermentation, and why, even when preserved with cane sugar, they will, in consequence of the acids they retain, slowly change the latter into grape-sugar, and thus induce fermentation.*

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* Milk also, in favorable circumstances, as when kept at a temperature of 100° F., undergoes fermentation, and in some countries of Asia, a spirituous liquor is prepared from mares' and asses' milk. In this case the milk first becomes sour, then the acids thus formed converts the milk sugar into grape

§ 8. *Of substances which contain Nitrogen.—Gluten, Vegetable Albumen, and Diastese.*

The substances described in the preceding sections consist of carbon, hydrogen, and oxygen only, and of them the great bulk of the vegetable productions of the globe consists. But there are certain other circumstances occurring along with starch and sugar, into which nitrogen enters as a constituent, and which, though not formed in the vegetable kingdom in very large quantity, are yet of such interest and importance in other respects, as to make it necessary shortly to advert to them.

1°. *Gluten.*—When the flour of wheat is made into a dough, and this dough is washed with water upon a fine sieve, a milky liquid passes through, from which starch gradually subsides. This has been already stated. But on the sieve, when the water ceases to go through milky, there remains a soft adherent, tenacious and elastic substance, which can be drawn out into long strings, has scarcely any colour, taste, or smell, and is scarcely diminished by washing either with hot or with cold water. This substance is the *gluten* of *wheat.* The flour of other kinds of grain also yield it by a similar treatment, though generally in much smaller quantity. This appears from the following table:—The grain of

Wheat contains	8 to 35	per cent.	of gluten.
Rye . . .	9 to 13	"	"
Barley . . .	3 to 6	"	"
Oats . . .	2 to 5	"	"

When the moist gluten is dried in the air or at the temperature of boiling water, it diminishes much in bulk, and hardens into a brittle semi-transparent yellow substance resembling horn or glue. In this state it is insoluble in water,

sugar, and finally this sugar enters into fermentation. This takes place more readily in consequence of the presence of the decomposing cheesy matter (casein) of the milk—as is shown by the fact that the introduction of a small quantity of the curd of milk into a solution of grape sugar will cause it to ferment.

but dissolves readily in vinegar, in alcohol either cold or hot, and in solutions containing caustic* potash, or soda.

2°. *Vegetable albumen.*—To the white of egg the name of albumen (*albus* white) has been given by chemists. It possesses the well known property of coagulating or of forming a white solid insoluble substance, when it is heated either alone or after being mixed with water.

When the starch has subsided from the milky liquid which passes through the sieve in preparing the gluten of wheat, the water rests transparent and colourless above the white sediment. If this water be heated, it will become more or less troubled, and white films or particles will separate, which may be easily collected, and which possess all the properties of coagulated albumen, or boiled white of egg. To this substance the name of *vegetable albumen* has been given. When the fresh prepared *gluten* of wheat is boiled in alcohol a portion of albumen generally remains undissolved, showing that water does not completely wash it out from the gluten.

Vegetable albumen, when fresh and moist, has neither colour, taste, nor smell, is insoluble in water or alcohol, but dissolves in vinegar and in caustic potash or soda. When dry it is brittle, more or less coloured, and opaque. In the seeds of plants, it exists only in small quantity—thus the grain of

Wheat contains	$\frac{3}{4}$	to	$1\frac{1}{2}$	per cent.
Rye . .	2	to	$3\frac{3}{4}$	"
Barley . .	$\frac{1}{10}$	to	$\frac{1}{2}$	"
Oats . .	$\frac{1}{5}$	to	$\frac{1}{2}$	"

It occurs more largely however in the fresh juices of plants, in those of cabbage leaves, turnip roots, and many others. When these juices are heated the albumen coagulates and is readily separated.

Gluten and vegetable albumen appear to be as closely related as sugar and starch are to each other. Like these two substances, they consist of the same elements, united together in the same proportions, and are capable of similar mutual transformations. According to the most recent analyses, those of Dr. Scheerer, they consist of

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* The common *pearl-ash* or *soda* of the shops boiled with quick-lime.

Carbon	=	54·76
Hydrogen	=	7·06
Oxygen	=	20·06
Nitrogen	=	18·12
		100

When exposed to the air in a moist state these substances undergo decomposition. They ferment, emit a most disagreeable odour, and produce, among other compounds, vinegar and ammonia.

The important influence which gluten and vegetable albumen are supposed to exercise over the nourishing properties of the different kinds of food in which they occur, will be considered in a subsequent part of these lectures.*

3°. *Diastase.*—When cold water is poured upon barley newly malted and crushed, is permitted to remain over it for

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* There occur in the animal kingdom—in the bodies of animals—three other forms of the substance above described under the names of gluten and vegetable albumen. These are albumen or white of egg, already mentioned, —*casein*, the curd of cheese,—and *fibrin*, the substance of the muscular fibre of animals.

1°. *Casein.*—When the curd of cheese is well washed with water, and then boiled in alcohol to free it from oily matter, it forms the casein of chemists. While moist it is soft and colourless, but as it dries it hardens, assumes a yellow colour, and becomes semi-transparent. Even when moist it is perfectly insoluble either in cold or in hot water. It is soluble, however, in water containing vinegar, or to which a little carbonate of potash or soda has been added. It may be kept for any length of time in a dry place, without undergoing decay. The changes undergone by old cheese are chiefly due to the oily and other substances with which the curd is mixed. It has been remarked, that when the gluten of wheat is left for a length of time in a moist state it undergoes a kind of fermentation and gradually acquires the smell and taste of cheese (Rouelle.)

2°. *Fibrin.*—When lean beef or mutton is long washed in water till it becomes colourless, and is then boiled in alcohol to separate the fat, a colourless, elastic, fibrous mass is obtained, which is the fibrin of chemists. In recently drawn blood it exists in the liquid state, but coagulates spontaneously when exposed to the air, and forms the greater part of the *clot* of blood. It dissolves in a solution of caustic potash or of nitre, and in vinegar.

3°. *Albumen.*—This substance in the liquid state exists in the white a quarter of an hour, is then poured off, filtered, evaporated to a small bulk over boiling water, again filtered if necessary, and then mixed with much alcohol, a white tasteless powder falls—to which the name of *diastase* has been given.

of egg, and in the serum of the blood. It coagulates by heating to 160° F., or if previously mixed with water by raising to 212° F.

These three substances, in addition to their well known sensible properties, are distinguished as follows:

1°. *Liquid casein* in milk, is not coagulated by heating *alone*—the addition of rennet or of a little acid (vinegar or spirit of salt) is necessary, when it curdles readily.

2°. *Liquid albumen* in white of egg, coagulates by heat alone, as when an egg is put into hot water.

3°. *Liquid fibrin* in the blood coagulates by mere exposure to the air, or more rapidly by agitation in contact with the air.

Like starch and sugar these three substances are mutually convertible by known means. Thus *fibrin*, if unboiled, dissolves by digestion at 80° F. in a saturated solution of nitre, and acquires the properties of *liquid albumen*; and if to *liquid albumen* a little caustic potash be added, and afterwards much alcohol, it will be thrown down in the form and with the properties of *casein*.

All these substances appear to contain the same organic constituents in the same proportions.

Boussingault first shewed the identity in chemical constitution of gluten and vegetable albumen.[*] Mulder afterwards proved a similar identity between vegetable albumen and the white of egg, fibrin, and casein.[†] Mulder supposes them to differ from each other by the presence in unlike quantities of a small admixture of sulphur, phosphorus or phosphate of lime.

Those who are not familiar with the history and with the nature of chemical research, can form no idea of the time and labour which has by different chemists been expended on this one branch. The persevering industry of Dr. Mulder, of Rotterdam, appeared to have cleared up the entire subject by a long series of investigations and analyses,[‡] when first Vogal, then Prosper Denis, and latest Liebig and Dr. Scheerer, have arrived at different results. Our ideas are thus again unfixed, and our partial generalizations set aside for future emendation.

The analysis inserted in the text, as representing the composition of gluten and vegetable albumen, is that given by Dr. Scheerer for the purest form of *fibrin*. I have selected it in preference to the results either of Boussingault or of Mulder, because it is the most recent, and has been obtained with a knowledge of all the previous researches,—and assuming the chemical identity of this entire group of substances, is the

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[* Pog. An. xl. p. 253.]

[† Ann. de Chim. et de Phys. lxv., p. 301.]

[‡ For an outline of his results, see Berzelius Årsberättlese, 1839, p. 611.]

If unmalted barley be so treated no diastase is obtained. This substance, therefore, *is formed during the process of malting.*

If wheat, or barley, or potatoes, which by steeping in water yield no diastase, be made to germinate (or sprout), and be afterwards bruised and treated as above, diastase will be obtained. *It is therefore produced during germination.*

If the shoot of a potato be cut off within half an inch of its base, this lower portion with the part of the potato to which it is immediately attached, separated from the rest—and the three parts (the upper portion of the shoot—the lower portion with its attached fragment of potato—and the remaining mass of the potato) treated with water,—only that portion will yield diastase in which the base of the shoot is situated. When a seed sprouts, therefore, *this substance is formed at the base of the germ*, and there remains during its growth.

If the same portion of the potato, or if the grain of barley or wheat is examined, when the first true leaves of the plant have been fully formed and expanded, the diastase will be found to have in great part, if not entirely, disappeared. This substance, therefore, is first formed when the seed begins to sprout, performs a function which makes its presence necessary at the base of the germ, and which function being discharged when the true leaves are formed, it then disappears. What is the nature of this temporary function, why the diastase must reside at the base of the sprout in order to discharge it, and why it should so early cease, will appear from a detail of the properties of this singular substance.

Properties of diastase.—If the solution obtained from malt be digested with potato, flour, or other starch, at a temperature between 120° and 140° F., the latter will gra-

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most likely to represent their constitution with accuracy. It differs from the analysis of Mulder *only* in stating the nitrogen at 2 per cent. higher than was done by that chemist. The recent improvements in the mode of determining the true quantity of nitrogen in organic substances, appear to justify us in expecting the result of Scheerer to be in this respect the more correct.

dually dissolve and will form a colourless transparent solution. When this solution is carefully evaporated a yellowish white powder is obtained, perfectly soluble in water, to which the name of *dextrine*[*] has been given. This dextrine has the same composition as starch. It is merely starch changed or transformed in such a way as to become soluble in cold water,—a change analogous to that which it undergoes by simply boiling in water.

But if the digestion be continued after the starch is dissolved, the solution will gradually acquire a sweet taste, and if it be now evaporated it will yield, instead of dextrine, a mixture of gum and grape-sugar. And if the digestion be still further prolonged, the whole of the starch will be converted into grape sugar only.[†]

Thus *diastase* (like sulphuric acid) possesses the property of transforming starch entirely—first into gum, and then into grape sugar. The intermediate stage of dextrine has not been recognised in the action of sulphuric acid, nor is it easy to arrest the action of diastase exactly at this point—the most carefully prepared dextrine always containing a mixture of gum and sugar. One part of diastase will convert into sugar 2000 parts of starch.

A solution of diastase, when allowed to stand, soon undergoes decomposition, and after being boiled, it has no further effect upon starch. It has not been analyzed, because it is difficult to obtain it in a pure state. It contains nitrogen, however, for, when moistened and exposed to the air, it decomposes, and, among other products, yields ammonia.[‡]

The functions of diastase—one of the purposes at least for which it is produced in the living seed, and situated at the base of the germ—will now be in some measure understood. The starch in the seed is the food of the future germ, prepared and ready to minister to its wants whenever heat and moisture concur in awakening it to life. But starch is itself insoluble in water, and could not, therefore, accompany the fluid sap when it begins to move and circulate. For this reason diastase is formed at the point where the germ first issues from the mass of food. There it transforms the starch, and renders it soluble, so that the young vessels can take it up and convey it to the point of growth. When the starch is exhausted its functions cease. It is then itself transformed and carried into the general circulation. Or when, as in the potato, much more starch is present than is in many cases requisite, its function ceases long before the whole of the starch disappears. Its presence is necessary only until the leaves and roots are fully formed—when the plant is enabled to provide for itself, and becomes independent of the starch of the seed. When this period arrives, therefore, the production of diastase is no longer perceived.

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[*] Because its solution turns to the *right* a ray of polarized light when passed through it.

[†] See above § 6, p. 166.

[‡] It will be recollected that ammonia contains nitrogen, being represented by NH^3. See Lecture III., p. 68.

This I have said is one of the purposes which appears to be served by diastase in the vegetable economy. That it is the only one we have no reason to believe. There may be others quite as interesting which we do not as yet understand. This is rendered more probable by the fact that the diastase contained in one pound of malted barley is capable of converting into sugar five ponnds* of starch. (Liebig.) And though at the temperature at which the seed germinates, more of this substance may be necessary to transform the same weight of starch than is required in our hands, when aided by artificial heat,—yet as we never in the ordinary course of nature find any thing superfluous or going to waste, there is reason to believe that the diastase may be intended also to contribute directly to the nourishment and growth of the plant. As it contains nitrogen, it must be derived from the gluten or vegetable albumen of the seed; and as a young plant of wheat, when already many inches from the ground, contains no more nitrogen than was originally present in the seed itself (Boussingault), this diastase may only be the result of one of those transformations of which gluten* is susceptible, and by which it is rendered soluble, and capable of aiding in the production of those parts of the substance of the growing plant into which nitrogen enters as a necessary constituent.

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* It is the diastase in malt which dissolves the starch of the barley in the process of brewing, but as the diastase, contained in malt is sufficient to dissolve so large a quantity of starch, it is obviously a waste of labour to malt the whole of the barley employed. One of malt to three of barley would probably be sufficient in most cases to obtain a wort containing the whole of the starch in solution. Advantage is taken of this property in the manufacture of the *white beer* of Louvain, and of other places in Flanders, and in Germany, where the light colour is secured by adding a large quantity of flour to a decoction of a small quantity of barley.

It may not be uninstructive if we pause here for a moment and consider the beauty of the arrangements we have just been describing. In passing through a new and interesting country we do not hesitate, at times, to stop and gaze, and leisurely admire. We cannot otherwise fully realize and appreciate its beauty. So in the domains of science, we cannot be ever hurrying on—we must linger occasionally, not only that we may more carefully observe, but that we may meditate and feel.

You see how bountifully nature has provided in the seed for the nourishment of the young plant, how carefully the food is stored up for it, and in how imperishable a form—how safely covered also and protected from causes of decay! For hundreds of years the principle of life will lie dormant, and for as many the food will remain sound and undiminished till the time of awakening comes. Though buried deep in the earth, the seed defies the exertions of cold or rain, for the food it contains is unaffected by cold and absolutely insoluble in water. But no sooner is the sleeping germ recalled to life, by the access of air and warmth and duly tempered moisture, than a new agent is summoned to its aid, and the food is so changed as to be rendered capable of ministering to its early wants. The first movement of the nascent germ (and how it moves, by what inherent or impartial force, who shall discover to us?)—is the signal for the appearance of this agent—diastase—of which, previous to germination, no trace could be discovered in the seed. At the root of the germ, where the vessels terminate in the farinaceous matter, exactly where it is wanted, this substance is to be found;—there, and there only, resolving and transforming the otherwise unavailable store of food, and preparing it for being conveyed either to the ascending sprout or to the descending root. And when the necessity for its presence ceases—when the green leaf becomes developed, and the root has fairly entered the soil—when the plant is fitted to seek food for itself—then this diastase disappears, it undergoes itself a new conversion, and is prepared in another form to contribute to the further increase of the plant.

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* That *diastase* is merely *transformed* gluten we cannot say, because the exact chemical constitution of diastase is as yet unknown.

How beautiful and provident are all these arrangements!—how plastic the various forms of organic matter in the hands of the All-Intelligent!—how nicely adjusted in time and place its diversified changes! What an apparently lavish expenditure of forethought and kind provision, in behalf even of the meanest plant that grows!

§ 9. *Vegetable acids.—Acetic acid, Oxalic acid, Tartaric acid, Citric acid, Malic acid.*

Another class of compound substances remains to be shortly considered,—those, namely, which possess sour or acid properties, and which are known to be present in large quantity in many plants, and more especially in the greater number of unripe fruits. They do not, taken as a whole, form any large portion of the entire produce, either of the general vegetation of the globe or of those plants which are cultivated for food; yet the growth of fruit—as in the grape, orange, and apple countries—is sufficiently extensive, and the general interest in the cultivation of fruit trees sufficiently great, to require that the nature of the substances contained in fruits, and the peculiar changes by which they are formed, should be in some measure considered and explained.

I.—ACETIC ACID.

Acetic acid or vinegar is the most extensively diffused, and the most largely produced, of all the organic acids. It is formed during the germination of seeds, and it exists in the juices of many plants, but it is most abundantly evolved during the fermentation, whether natural or artificial, of nearly all vegetable substances. When pure it is a colourless liquid, having a well known agreeably acid taste. It may be boiled and distilled over without being decomposed. The vinegar of the shops is generally very much diluted, but it can be prepared of such a strength as to freeze and become solid at 45° F., and to blister the skin and produce a sore when applied to any part of the body. When mixed with water it readily dissolves lime, magnesia, alumina, &c., forming *salts* called *acetates*, which are all soluble in water, and may, therefore, be readily washed out of the soil or of compost heaps by heavy falls of rain.

When perfectly free from water, acetic acid consists of—

Carbon . . .	47·5 per cent., or 4 atoms.
Hydrogen . . .	5·8 per cent., or 3 atoms.
Oxygen . . .	46·7 per cent., or 3 atoms.
	100

It is therefore represented by the formula $C^4 H^3 O^3$—in which, as in those given in the preceding sections for starch, sugar, &c., the numbers representing the atoms of hydrogen and oxygen are equal, and consequently these elements are in the proportion to form water. Hence vinegar, like sugar, may be represented by carbon and water.

Let us consider for a moment the several processes by which this acid is usually formed.

1°. *By the distillation of wood.*—This is a method by which wood vinegar—often called *pyroligneous acid*—is prepared in large quantity. Wood which has been dried in the air is put into an iron retort and distilled. The principal products are vinegar, water, and tarry matter. The decomposition is of a complicated description, but by comparing the constitution of woody fibre with that of vinegar, we can readily see the nature of the changes by which the latter is produced.

$$\begin{array}{rl} \text{Woody Fibre is} = & C^{12}\ H^{8}\ O^{8} \\ \text{3 of Vinegar are} = & C^{12}\ H^{9}\ O^{9} \\ \hline \text{Difference} = & \quad\ H^{1}\ O^{1} \end{array}$$

; or the elements of one atom of water. One portion of the woody fibre, therefore, combines with the elements of an atom of water, obtained by the decomposition of another portion, and thus vinegar is produced.

2°. *Manufacture of Vinegar from Cane-sugar.*—It is a well known fact in domestic economy, that if cane-sugar be dissolved in water, a little vinegar added to it, and the solution kept for a length of time at a moderate temperature, the whole will be converted into vinegar without any sensible fermentation. This process is frequently followed in the preparation of household vinegar, and was formerly adopted to some extent in our chemical manufactories. It will be recollected that we represented

$$\begin{array}{ll} \text{CANE SUGAR by} & C^{12}\ H^{10}\ O^{10}, \text{ while} \\ \text{3 of VINEGAR} = & C^{12}\ H^{9}\ O^{9} \\ \hline \text{Difference} & H^{1}\ O^{1} \end{array}$$

; or the elements of an atom of water, which cane-sugar must *lose* in order to be converted into vinegar. Whether the change in this instance takes place by the direct conversion of cane-sugar into vinegar, or whether the former is previously transformed into grape sugar, has not been satisfactorily determined.

3°. *Manufacture of Vinegar from Alchohol.*—In Germany, where common brandy is cheaper than vinegar, it is found profitable to manufacture this acid from weak spirit.

For this purpose it is mixed with a little yest, and then allowed to trickle over wood shavings moistened with vinegar, and contained in a cask, the sides of which are perforated with holes for the admission of a current of air. By this method oxygen is absorbed from the air, and in 24 hours the alcohol in the spirit is converted into vinegar and water.

The explanation of this process is also simple, alcohol b eing represented by $C^{4}\ H^{6}\ O^{2}$ Thus—

$$\left.\begin{array}{lr} \text{ALCOHOL} = & C^{4}\ H^{6}\ O^{2} \\ \text{4 of OXYGEN} = & O^{4} \\ \hline & C^{4}\ H^{6}\ O^{6} \end{array}\right\} = \left\{\begin{array}{lr} \text{VINEGAR} = & C^{4}\ H^{3}\ O^{3} \\ \text{3 of WATER} = & H^{3}\ O^{3} \\ \hline \text{Sum} & = C^{4}\ H^{6}\ O^{6} \end{array}\right.$$

Sum

4°. *Production of Vinegar by fermentation.*—When vegetable matters are allowed to ferment, carbonic acid is given off and vinegar is formed. In such cases this acid is the result of a series of changes, during which that portion of the vegetable matter which has at length reached the state of vinegar has most probably passed through the several previous stages of grape, sugar, and alcohol. The carbonic acid, as has already been explained (p. 169,) is given off during the fermentation of the grape-sugar, and the consequent formation of alcohol.

To simple transformations, similar to those above described, we can trace the origin of the vinegar which is met with in the living juices of plants, and among the products of their decay.

II.—TARTARIC ACID.

The grape and the tamarind owe their sourness to a peculiar acid to which the name of *tartaric acid* has been given. It is also present, along with other acids, in the mulberry, in the berries of the sumach (*rhus coriarii*,) and in the sorrels, and has been extracted from the roots of the couch-grass and the dandelion.

When new wine is decanted from the lees, and set aside in vats or casks, it gradually deposits a hard crust or *tartar* on the sides of the vessels. This substance is known in commerce by the name of argol, and when purified is familiar to you as the cream of tartar of the shops. It is a compound of tartaric acid with potash, and from it tartaric acid is extracted for use in medicine and in the arts. The principal use of the acid is in certain processes of the calico printers.

The pure acid is sold either in the form of a white powder or of transparent crystals, which are colourless, and have an agreeable acid taste. It dissolves readily in water, and causes a violent effervescence when mixed with a solution of the carbonate of potash or of soda. As it has no injurious action upon the system, it is extensively used in artificial soda powders and effervescing draughts. When added in sufficient quantity to a solution containing potash, it causes a white crystalline powder to fall, which is cream of tartar (or *bitartrate of potash*), and from lime water it throws down a white chalky precipitate of *tartrate of lime*. Both of these compounds are present in the grape.

When perfectly free from water this acid consists of—

Carbon . .	= 36·81	or 4 atoms.
Hydrogen . .	= 3·00	or 2 atoms.
Oxygen . .	= 60·19	or 5 atoms.
	100	

It is, therefore, represented by the formula $C^4 H^2 O^5$.

If we compare the numbers by which the atoms of hydrogen and oxygen in this acid are expressed, we see that these elements are not in the proportion to form water, and that this substance, therefore, cannot, like so many of those we have hitherto had occasion to notice, be represented by carbon and the elements of water *alone*.

It may be represented by

$$\left.\begin{array}{lll} \text{4 of CARBON . .} = & C^4 & \\ \text{2 of WATER . .} = & & H^2\,O^2 \\ \text{and 3 of OXYGEN . .} = & & O^3 \end{array}\right\} \text{ or, } 4C+2HO+3O$$

$$\text{TARTARIC ACID} = C^4\,H^2\,O^5$$

And, though this mode of representation does not truly exhibit the constitution of the acid, inasmuch as we have no reason to believe that it really contains water as such—yet it serves to show very clearly that in the living plant this acid cannot be formed *directly* from carbon and the elements of water, as starch and sugar may, but that it requires also *three atoms of oxygen in excess* to every five of carbon and two of water. We shall, in the following lecture, see how nicely the functions of the several parts of the plant are adjusted,—at one period to the formation of this acid, and at another to its conversion into sugar during the ripening of the fruit.

III.—CITRIC ACID OR ACID OF LEMONS.

This acid gives their sourness to the lemon, the lime, the orange, the cranberry, the red whortleberry, the bird-cherry, and the fruits of the dog-rose and the woody night-shade.

It is also found in some roots, as in those of the dahlia pinnata, and the asarum europæum (*asarrabacca*), and mixed with much malac acid, in the current, cherry, gooseberry, raspberry, strawberry, common whortleberry, and the fruit of the hawthorn.

When extracted from the juice of the lemon or lime, and afterwards purified, it forms transparent colourless crystals, possessed of an agreeable acid taste; effervesces like tartaric acid with carbonate of soda, and like it, therefore, is much employed for effervescing draughts. With potash it forms a soluble salt, which is a *citrate of potash*, and from lime water it throws down a white, nearly insoluble, sediment of *citrate of lime*, which re-dissolves when the acid is added in excess. In combination with lime it exists in the tubers, and with potash in the roots, of the Jerusalem artichoke.

When free from water, citric acid consists of

Carbon . .	41·49	= 4 atoms.
Hydrogen . .	3·43	= 2 atoms.
Oxygen . .	55·08	= 4 atoms.
	100	

and is therefore represented by $C^4 H^2 O^4$.

This formula differs from that assigned to the tartaric acid only in containing one atom of oxygen less, O^4 instead of O^5. In the citric acid, therefore, there are 2 atoms of oxygen in excess, above what is necessary to form water with the 2 of hydrogen it contains.

I.—MALIC ACID.

The malic and oxalic acids are more extensively diffused in *living* plants than any other vegetable acids. If acetic acid be more largely formed in nature, it is chiefly as a product of the decomposition of organic matter when it has already ceased to exist in, or to form part of, a living plant.

Along with the citric acid, it has been already stated that the malic occurs in many fruits. It is found more abundantly, however, and is the chief cause of the sour taste, in the unripe apple,[*] the plum, the sloe, the elderberry, the

[*] Hence its name *malic* acid.

barberry, the fruit of the mountain ash, and many others. It is associated with the tartaric acid in the grape and in the Agave americana.

This acid is not used in the arts or in medicine, and therefore is not usually sold in the shops. It is obtained most readily, in a pure state, from the berries of the mountain ash. It forms colourless crystals, which have an agreeable acid taste. It combines with potash, soda, lime, and magnesia, and forms *malates*, and, in combination with one or more of these bases, it usually occurs in the fruits and juices of plants. The *malate* of lime is soluble, while the citrate as already stated, is nearly insoluble, in water. This malate exists in large quantity in the juice of the house-leek (*sempervivum tectorum*) in the Sedum telephium, the Arum maculatum, and many other juicy and fleshy-leaved plants.

When perfectly free from water, the malic acid has exactly the same chemical constitution as the citric, and is represented by the same formula $C^4 H^2 O^4$. These two acids, therefore, bear the same relation to each other as we have seen that starch, gum, and sugar do. They are what chemists call *isomeric*, or are *isomeric* bodies. We cannot transform them, however, the one into the other, by any known means, though there is every reason to believe that they may undergo such transformations in the interior of living plants. Hence probably one reason also why the malic and citric acids occur associated together in so many different fruits.

V.—OXALIC ACID.

This acid has already been treated of, and its properties and composition detailed, in a preceding lecture (Lecture III. p. 61). It forms colourless transparent crystals, having an agreeably acid taste, and it effervesces with the carbonates of potash and soda, but on account of its poisonous qualities, it is unsafe to administer it as a medicine. It occurs in combination with potash in the sorrels, in rhubarb and in the juices of many lichens. Those lichens which incrust the sides of rocks and trees, not unfrequently contain half their weight of this acid in combination with lime. It can be formed artificially by the action of the nitric acid on starch, sugar, gum, and many other organic substances.

When perfectly free from water, oxalic acid contains no hydrogen; but consists of—

Carbon - - -	33·75	= 2 atoms.
Oxygen - - -	66·25	= 3 atoms.
	100	

and it is represented by $C^2 O^3$. When heated with strong sulphuric acid, it is decomposed and resolved into gaseous carbonic acid ($C O^2$) and carbonic oxide ($C O$) in equal volumes. This change is easily understood since $C O^2 + C O = C^2 O^4$.

§ 10. *General observations on the substances of which plants chiefly consist.*

It may be useful here shortly to review the most important facts and conclusions which have been adverted to in the present lecture.

1°. The great bulk of plants consists of a series of substances capable of being represented by and consequently of being formed in nature from, carbon and the elements of water only. Such are woody fibre, starch, gum, and the several varieties of sugar (p. 162).

2°. Yet the crude mass of wood, as it exists in a full-grown tree, containing various substances in its pores, cannot be represented by carbon and the elements of water *alone*. It appears always to contain a small excess of hydrogen, which is greater in some trees than in others. Thus in the chesnut and the lime, this excess is greater than in the pines, while in the latter it is greater than in the oak and the ash.*

3°. These substances are, in many cases, mutually convertible even in our hands. They are probably, therefore, still more so in nature.

It is to be observed, however, that all the transformations we can as yet effect are in one direction only. We can produce the above compounds from each other in the order of lignin or starch, gum, cane-sugar, grape-sugar—that is, we can convert starch into gum, and gum into sugar, but we cannot reverse the process, so as to form cane from grape-sugar, or starch from gum.

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* For a series of analyses of different kinds of wood by Petersen and Schödler, see Thomson's *Organic Chemisty*, p. 849.

The only apparent exception to this statement with which we are at present acquainted, occurs in the case of starch. When this substance is dissolved in *cold* concentrated nitric acid, and then mixed largely with water, a substance[*] falls to the bottom which is a compound of the nitric acid with woody fibre (C^{12} H^{8} O^{8}).[†] In this instance if the above observation is correct, there appears to be an actual conversion of starch into woody fibre.

But what *we* are as yet unable to perform may, nevertheless, be easily and constantly effected in the living plant. Not only may what is starch in one part of the tree be transformed and conveyed to another part in the form of sugar,—but that which, in the form of sugar or gum, passes upwards or downwards with the circulating sap, may, by the instrumentality of the vital processes, be deposited in the stem in the form of wood, or in the ear in that of starch. Indeed we know that such actually does take place, and that we are still, therefore, very far from being able to imitate nature in her power of transforming even this one group of substances only.

4°. Among, or in connection with, the great masses of vegetable matter which consist mainly of the above substances, we have had occasion to notice a few which contain nitrogen as one of their constituents—and which, though forming only a small fraction of the products of vegetable growth yet appear to exercise a most important influence in the general economy of animal as well as of vegetable life. The functions performed by diastase in reference to vegetable growth, and to the transformations of organized vegetable substances, have already been in some measure illustrated,—we shall hereafter have an opportunity of considering more fully the influence which gluten and vegetable albumen exercise over the general efficiency of the products of vegetation in the support of animal life, and over the changes which these products must undergo, before they can be converted into the substance of animal bodies. In a former lecture (Lecture IV. p. 91,) I have had occasion to draw your attention to the comparatively small proportion in which nitrogen exists in the vegetable kingdom, and to show that it must nevertheless be considered as much a necessary and constituent element in their composition as the carbon itself; the very remarkable properties we have already discovered in the compounds above mentioned strongly confirm this fact, and illustrate in a striking manner the influence of apparently feeble and inadequate causes in producing important natural results.

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[*] The *Xyloidin* of Braconnot.

[†] Pelouze, see Berzelius *Asberättelse*, 1839, p. 416.

5°. With the exception of acetic acid, which in constitution is closely related to sugar* and gum, all the acid substances to which it has been necessary to advert, contains an excess of oxygen above what is necessary to form water with the hydrogen they contain. Thus

VINEGAR $= C^4\,H^3\,O^3$ contains no excess of oxygen.
TARTARIC ACID $= C^4\,H^2\,O^5$ . . . 3 of oxygen in excess.
MALIC ACID, CITRIC ACID $\Big\} = C^4\,H^2\,O^4$ . . . 2 . . . . . .
OXALIC ACID $= C^2\,O^3$ . . . 3 . . . . . .

It requires a little consideration to enable us to appreciate the true importance of these and other organic acids, in the vegetable economy. At first sight they appear to form a much smaller part of the general products of vegetation than is really the case. We must endeavour to conceive the quantity actually produced by a single tree loaded with thousands of lemons, oranges, or apples,—or again how much is formed during the growth of a single comparatively

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* It is identical in constitution with *caramel* (p. 167)—the uncrystallizable sugar of syrups. For

$$\overset{\text{Vinegar.}}{(C^4\,H^3\,O^3 \times 3)} = \overset{\text{Caramel.}}{C^{12}H^9\,O^9}.$$

small plant of garden rhubarb in spring, if we would obtain an adequate idea of the extent to which these acids are constantly formed in nature. On the other hand, we must recollect also that the greater portion of the acid of fruits disappears as they ripen, if we would understand the true nature of the interest which really attaches to the study of these substances, of the changes to which they are liable, and of the circumstances under which in nature these changes take place.

6°. I will venture here to draw your attention for a moment to the nature and extent of that remarkable power over matter, which the chemist, as above explained, appears to possess. Such a consideration will be of value not only in illustrating how far we really can now, or may hereafter, expect to be able to influence or control natural operations,* but what is probably of more value still, in exhibiting the true relation which man bears to the other parts of creation; and, therefore, in some measure, the true position he is intended to occupy among them.

1°. We have seen that the chemist can *transform* certain substances one into the other, in a known order; but that as yet he cannot reverse that order. Thus far his power over matter is at present limited; but this limit he may at some future period be able to overpass, and we know not how far. The discovery of a new agent, or of a new mode of treatment, may enable him to accomplish what he has not as yet the means or the skill to perform.

2°. He has it in his power to form, actually to produce, some of the organic or organized substances which occur in living plants. He can form gum, and grape-sugar, in any quantity. *Thus far he can imitate and take the place of the living principle itself.*

Numerous other cases are known, in which he displays a similar power. By the action of nitric acid upon starch† or sugar, he can form *oxalic acid*, which, as has already been shown, occurs very largely in the vegetable kingdom. By the action of heat upon citric acid, he can decompose it and produce an acid which is met with in the Wolfsbane (Aconitum napellus), and hence is called *aconitic acid.*[*] Also by the action of sulphuric acid he can change *salicine* and *phlorizine*—substances extracted respectively from the bark of the willow and from that of the root of the apple-tree—into a resinous matter and *grape-sugar*. So, of the compounds which are found in the solids and fluids of animal bodies, there are some, which he has also succeeded in forming by the aid of his chemical art.

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* See Lecture II., p. 37.

† See Lecture III., p. 61.

Elated by such achievements, some chemists appear willing to hope that all nature is to be subjected to their dominion, and that they may hereafter be able to rival the living principle in all its operations. It is true that what we now know, and can accomplish, are but the beginnings of what we may fairly expect hereafter to effect. But it is of consequence to bear in mind the true position in which we now stand, and the true direction in which all we at present know seems to indicate that our future advances in knowledge, and in control over nature, are likely to proceed. And this leads me to observe—

3o. That our dominion is at present limited solely to tronsforming and decomposing. We can *transform* woody fibre into gum or sugar—*we cannot form either gum or sugar by the direct union of their elements.* We can *resolve* salicine by the acid of sulphuric acid into resin and grape-sugar; but we cannot cause the elements of which they consist to unite together in our hands, so as to form any one of the three. We cannot even cause the resin and the sugar to re-unite and rebuild the salicine from which they were derived.

So we can by heat drive off the elements of water from

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[*] These two acids differ from each other only by the elements of an atom of water. Thus

$$\begin{array}{lcl} \text{Citric Acid} \;\ldots & = & C^4\ H^2\ O^4 \\ \text{Aconitic Acid} \;\ldots & = & \underline{C^4\ H^1\ O^3} \\ \text{Difference} \;\ldots\ldots & = & \quad H^1\ O^1 \text{ or HO, one of water.} \end{array}$$

It is easy to see, therefore, how, by the evolution of the elements of an atom of water, the one acid may be changed into the other. The scientific reader will excuse me (if on the grounds of simplicity alone) for representing, both here and in the text, the citric acid by $C^4\ H^2\ O^4$, instead of by $C^{12}\ H^5\ O^{11} + 3\ HO$, which Liebig and his pupils prefer.

the citric and cause the aconitic acid to appear; but we cannot persuade the unwilling compounds, when thus separated, to return to their former condition of citric acid; and, if we could, we should still be as far removed from the power of commanding or compelling the direct union of carbon, hydrogen, and oxygen, in such proportions, and in such a way, as to build up either of the two acids in question.

Again, we can actually form oxalic acid by the action of nitric acid upon starch, or wood, or sugar, or any other of a great variety of vegetable substances—but we cannot prepare it by the direct union of its elements. We can only as yet procure it from substances which have already been *organized*—which have been themselves produced by the agency of the living principle.

The same remarks apply with slight alteration to those substances of animal origin, to which I have above alluded as being within the power of the chemist to produce at will. There is hardly an exception to the rule, that in producing *organic* substances, as they are called, the chemist must employ other organic substances which are as yet beyond his art—which, so far as we know, can only be formed under the direction of the living principle. Thus the sum of the chemist's power in imitating organic nature consists, at present, in his ability—

1°. To *transform* one substance found only in the organic kingdom into some other substances, produced more or less abundantly in the same kingdom of nature. This power he exercises when he converts starch into sugar, or fibrin into albumen or casein.

2°. To *resolve* a more complex or compound substance into two or more which are less so, and of which less complex substances some may be known to occur in vegetable or animal bodies.

3°. To decompose organic compounds by means of his chemical agents, and as the result of such decompositions to arrive at one or more compounds, such as are formed under the direction of the living principle.

In no one case can he form the substances of which animals and plants chiefly consist, out of those on which animals and plants chiefly live.

But this is the common and every-day result of the agency of the living principle. Is there as yet, then, any hope that the chemical laboratory shall supersede the vascular system of animals and plants; or that the skill of the chemist who guides the operations within it, shall ever rival that of the principle of life which presides over the chemical changes that take place in animal and vegetable bodies?

The true place, therefore, of human skill—the true prospects of chemical science—are pointed out by these considerations. No science has accumulated so many and such various treasures as chemistry has done during the last 20 years—none is at present so widely extending the bounds of our knowledge at this moment as the branch of organic chemistry—men may therefore be excused for entertaining more sanguine expectations from the progress of a favourite science than sober reasoning would warrant. Yet it is of importance, I think, and especially in a moral point of view, that amid all our ardor, we should entertain clear and just notions of the kind and extent of knowledge to which we are likely to attain, and—as knowledge in chemistry is really power over matter—to what extent this power is likely ever to be carried.

At present, if we judge from our actual knowledge, and not from our hopes—there is no prospect of our ever being able to imitate or rival living nature in actually compounding from their elements her numerous and varied productions. That we may clearly understand, and be able to explain many of her operations, and even to aid her in effecting them, is no way inconsistent with an inability to imitate her by the resources of art. This will, I trust, appear more distinctly in the subsequent lecture.

LECTURE VII.

Chemical changes by which the substances of which plants chiefly consist are formed from those on which they live. Changes during germination—during the growth of the plant—during the ripening of fruit. Autumnal changes.

Having thus considered the nature and chemical constitution of those substances which constitute by far the largest part of the solids and fluids of living vegetables, we are now prepared for the further question—*by what chemical changes these substances of which plants consist, are formed out of those on which they live.*

The growth of a plant, from the germination of the seed in spring till the fall of the leaf in autumn, or the return of the succeeding spring time, may in perennial plants be divided into four periods—during which they either live on different food, or expend their *main* strength in the production of different substances. These periods may be distinguished as follows :—

1°. The period of germination—from the sprouting of the seed to the formation of the perfect leaf and root.

2°. From the expansion of the first true leaves to the period of flowering.

3°. From the opening of the flower to the ripening of the fruit and seed.

4°. From the ripening of the seed or fruit, till the fall of the leaf and the subsequent return of spring. On the ripening of the fruit the functions of annual plants are in general discharged, and they die; but perennial plants have still important duties to perform in order to prepare them for the growth of the following spring.

The explanation of the chemical changes to which our attention is to be directed will be more clear, and perhaps more simple, if we consider them in relation to these several periods of growth.

§ 1. *Chemical changes which take place during germination and during the developement of the first leaves and roots.*

The general nature of the chemical changes which take place during germination is simple and easy to be comprehended.

Let us first consider shortly the phenomena which have been observed to accompany germination, and the circumstances which are most favourable to its rapid and healthy progress.

1°. Before a seed will begin to sprout, it must be placed for a time in a sufficiently moist situation. We have already seen how numerous and important are the functions which water performs in reference to vegetable life (Lecture II., p. 42,) in every stage of a plant's growth. In the seed no circulation can take place—no motion among the particles of matter—until water has been largely imbibed; nor can the food be conveyed through the growing vessels, unless a constant supply of fluid be afforded to the seed and its infant roots.

2°. A certain degree of warmth—a slight elevation of temperature—is also favourable, and in most cases necessary, to germination.

The degree of warmth which is required in order that seeds may begin to grow, varies with the nature of the seed itself. In Northern Siberia and other icy countries, plants are observed to spring up at a temperature but slightly raised above the freezing point (32° F.,) but it is familiar to every practical agriculturist, that the seeds he yearly consigns to the soil require to be protected from the inclemency of the weather, and sprout most quickly when they are stimulated by the warmth of approaching spring or by the heat of a summer's sun.

The same fact is familiarly shown in the malting of barley, where large heaps of grain are moistened in a warm atmosphere. When germination commences, the grain heats spontaneously, and the growth increases in rapidity as the heap of corn attains a higher temperature. It thus appears that some portion of that heat which the growth of the germ and radicles requires, is provided by natural processes in the grain itself; in some such way as in the bodies of animals, a constant supply of heat is kept up by the vital processes—by which supply the cooling effect of the surrounding air is continually counteracted.

We have seen in the preceding lecture, that the transformations of which starch and gum are susceptible, take place with greater certainty and rapidity under the influence of an elevated temperature. It will presently appear that such transformations are also effected during germination; there is reason, therefore, to believe that the external warmth which is required in order that germination may begin, as well as the internal heat naturally developed as germination advances, are both employed in effecting these tranformations. And, as the young sprout shoots more rapidly under the influence of a tropical sun, it is probable that those natural agencies in general, by which such chemical transformations are most rapidly promoted, are also those by which the progress of vegetation is in the greatest degree hastened and promoted.

3°. It has been observed that seeds refuse to germinate if they are entirely excluded from the air. Hence seeds which are buried beneath such a depth of soil that the atmospheric air cannot reach them, will remain long unchanged, evincing no signs of life—and yet, when turned up or brought near the surface, will speedily begin to sprout. Thus in trenching the land, or in digging deep ditches and drains, the farmer is often surprised to find the earth, thrown up from a depth of many feet, become covered with young plants, of species long extirpated from or but rarely seen in his cultivated fields.

4°. Yet light is, generally speaking, prejudical to germination. Hence the necessity of *covering* the seed, when sown in our gardens and corn fields, and yet of not so far burying it that the air shall be excluded. In the usual method of sowing broad-cast, much of the grain, even after harrowing, remains uncovered; and the prejudicial influence of light in preventing the healthful germination of such seeds is no doubt one reason why, by the method of dibbling, fewer seeds are observed to fail, and an equal return of corn is obtained from a much smaller expenditure of seed.

The reason why light is prejudicial to germination, as well as why the presence of atmospheric air is necessary, will appear from the following observation:—

5°. When seeds are made to germinate in a limited portion of atmospheric air, the bulk of the air undergoes no material alteration, but on examination, its oxygen is found to have diminished, and carbonic acid to have taken its place. Therefore, *during germination, seeds absorb oxygen gas and give off carbonic acid.*

Hence it is easy to understand why the presence of air is necessary to germination, and why seeds refuse to sprout in hydrogen, nitrogen, or carbonic acid gasses. *They cannot sprout unless oxygen be within their reach.*

We have seen also in a previous lecture that the leaves of plants in the sunshine give off oxygen gas and absorb carbonic acid,—while in the dark the reverse takes place. So it is with seeds which have begun to germinate. When exposed to the light they give off oxygen instead of carbonic acid, and thus the natural process is reversed. But it is necessary to the growth of the young germ, that oxygen should be absorbed, and carbonic acid given off—and as this can take place to the required extent only in the dark, the cause of the prejudicial action of light is sufficiently apparent, as well as the propriety of covering the seed with a thin layer of soil.

6°. During germination, vinegar (acetic acid) and diastase are produced. That such is the case in regard to the latter substance, has been proved in the previous lecture—(p. 174). That acetic acid is formed is shown by causing seeds to germinate in powdered chalk or carbonate of lime, when after a time *acetate of lime** may be washed out from the chalk (Braconnot) in which they have been made to grow. The acid contained in this acetate must have been formed in the seed, and afterwards excreted or thrown out into the soil.

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* *Acetate of lime* is a compound of acetic acid (vinegar) and lime, and may be prepared by dissolving chalk in vinegar. It is very soluble in water.

7°. When the germ has shot out from the seed and attained to a sensible length, it is found to be possessed of a sweet taste. This taste is owing to the presence of *grape-sugar* in the sap which has already begun to circulate through the vessels.

It has not been clearly ascertained whether the vinegar or the diastase is first produced when germination commences, but there seems little doubt that the grape-sugar is formed subsequently to the appearance of both.

8°. The young shoot which rises upwards from the seed consists of a mass of vessels, which gradually increase in length, and after a short time expand into the first true leaves. The vessels of this first shoot do not consist of unmixed woody fibre. It is even said that *no true wood is formed till the first true leaves are developed.*[*] The vessels of the young sprout, therefore, and of the early radicles, probably consist of the *cellular fibre* of Payen. They are unquestionably formed of a substance which is in a state of transition between starch or sugar and woody fibre, and which has a constitution analogous[†] to that of both.

Having thus glanced at the phenomena which attend upon germination, let us now consider the chemical changes by which these phenomena are accompanied.

1°. The seed absorbs oxygen and gives off carbonic acid. We have already seen that the starch of the seed ($C^{12} H^{10} O^{10}$) may be represented by carbon and water,—by $12C + 10 HO$. Now it appears that in contact with the oxygen of the atmosphere, a portion of the starch is actually separated into carbon and water, the carbon at the moment of separation uniting with the oxygen, and forming carbonic acid (CO^2). This acid is given off into the soil in the form of gas, and thence partially escapes into the air; but for what *immediate* purpose it is evolved, or how its formation is connected with the further development of the germ, has not hitherto been explained.

2°. The formation of acetic acid (vinegar) from the starch of the grain is also easy to comprehend. For as we have already seen

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[*] Lindley's *Theory of Horticulture.*

[†] By *analogous* I mean which may be represented by carbon and water.

STARCH . . . = $C^{12}\ H^{10}\ O^{10}$
3 of VINEGAR . . = $C^{12}\ H^{9}\ O^{9}$

Difference . . = $H^{1}\ O^{1}$; or the elements of an atom of water. Therefore, in this early stage of the growth of the germ a portion of the starch is deprived of the elements of an atom of water, and at the same time transformed into vinegar.

Why is this vinegar formed? It is almost as difficult to answer this question as to say why carbonic acid is evolved from the seed, though both undoubtedly serve wise and useful ends.

It has been explained in the preceding lecture how the action of dilute acids gradually changes starch into cane-sugar, and the latter into grape-sugar. While it remains in the sap of the sprouting seed, the vinegar may aid the diastase in transforming the insoluble starch into soluble food for the plant, and may be an instrument in securing the conversion of the *cane*-sugar, which is the first formed, into *grape*-sugar,—since cane-sugar cannot long exist in the presence of an acid.

After the acetic acid is rejected by the plant, it may act as a solvent on the lime and other earthy matters contained in the soil. Liebig supposes the especial function of this acid—the reason why it is formed in the germ and excreted into the soil—to be, to dissolve the lime, &c., which the soil contains, and to return into the pores of the roots, bearing in solution the earthy substances which the plant requires for its healthy growth. This is by no means an unlikely function. It is only conjectural, however, and since the experiments of Braconnot have shown that *acetate of lime*, even in small quantity, may be injurious to vegetation, it becomes more doubtful how far the formation of this compound in the soil, and the subsequent conveyance of it into the circulation of the plant, can be regarded as the special purpose for which acetic acid is so generally produced during germination.

3°. The early sap of the young shoot is sweet; it contains grape-sugar. This sugar is also derived from the starch of the seed. Being rendered soluble by the diastase formed at the base of the germ, the starch is gradually converted into grape-sugar as it ascends. The relation between these two compounds has been already pointed out.

STARCH . . . = $C^{12} H^{10} O^{10}$
GRAPE-SUGAR . = $C^{12} H^{12} O^{12}$

Difference . = $H^{2} O^{2}$; or the elements of two atoms of water. The water which is imbibed by the seed from the soil, forms an abundant source from which the whole of the starch, rendered soluble by the diastase, can be supplied with the elements of the two atoms of water which are necessary to its subsequent conversion into grape-sugar.

4°. The diastase is formed when the seed begins to sprout, at the expense of the gluten or vegetable albumen of the seed, but as its true constitution is not yet known, we cannot explain the exact chemical changes by which its production is effected.

5°. When the true leaf becomes expanded, true wood first appears in sensible quantity. By what action of the sun's rays upon the leaf the sugar already in solution in the sap is converted into woody fibre, we cannot explain. The conversion itself is *in appearance* simple enough, since

GRAPE-SUGAR . . = $C^{12} H^{12} O^{12}$, and
WOODY FIBRE . . = $C^{12} H^{8} O^{8}$

Difference . . = $H^{4} O^{4}$; or the former must part with the elements of four atoms of water only, to be prepared for its change into the latter. But the true nature of the *molecular*[*] change by which this transformation is brought about, as well as the causes which lead to it and the immediate instruments by which it is effected, are all still mysterious.

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[*] All bodies are supposed to consist of particles or *molecules* of exceeding minuteness, and all chemical changes which take place in the same mass of matter are supposed to be owing to the different ways in which these particles arrange themselves. We may form a remote idea of the way in which different positions of the same particles may produce different substances, by considering how different figures in Mosaic may be produced by different arrangements of the same number of equal and similar fragments of various colours.

§ 2. *Of the chemical changes which take place from the formation of the true leaf to the expansion of the flower.*

When the true leaf is formed the plant has entered upon a new stage of its existence. Up to this time it is nourished almost solely by the food contained in the seed,—it henceforth derives its sustenance from the air and from the soil. The apparent mode of growth is the same, the stem shoots upwards, the roots descend, and they consist essentially of the same chemical substances, but they are no longer formed at the expense of the starch of the seed, and the chemical changes of which they are the result, are entirely different.

1°. The leaf absorbs carbonic acid in the sunshine, and gives off oxygen in equal bulk.* It is in the light of the sun that plants increase in size—their growth, therefore, is intimately connected with this absorption of carbonic acid.

If carbonic acid be absorbed by the leaf and the whole of its oxygen given off again,† carbon alone is added to the plant by this function of the leaf. But it is added in the presence of the water of the sap, and thus is enabled by uniting with it to form, as *it may be directed*, or as may be necessary, any one of these numerous compounds which may be represented by carbon and water, (p. 163,) and of which, as we have seen, the solid parts of plants are chiefly made up.

There are two ways in which we may suppose the oxygen given off by the leaf to be set free, and the starch, sugar, and gum, to be subsequently formed.

A. The action of light on the leaf of the plant may directly *decompose the carbonic acid* after it has been absorbed, and cause the oxygen to separate from the carbon, and escape into the air;—while at the same instant the carbon thus set free, may unite with the water of the sap in different proportions, so as to produce either sugar, gum, or starch. Suppose 12 atoms of carbonic acid ($12\ CO^2$) to be thus decomposed, and their carbon to unite with 10 of water (10 HO), we should have

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* Such is *sensibly* the result of experiment. How far the result can be considered as universally true, will be examined hereafter.

† It will be recollected that carbonic acid contains its own bulk of oxygen gas: if, therefore, the leaf give off the same bulk of oxygen as it absorbs of carbonic acid, the result must be as stated in the text.

from 10 of CARBONIC ACID . = C^{12} which united
to 10 of WATER . . . = $H^{10}\ O^{10}$, would give

1 of GUM or of CANE SUGAR = $C^{12}\ H^{10}\ O^{10}$

while 24 of oxygen would be given off, *the whole of which would have been derived from the carbonic acid* absorbed by the plant.

B. Or the action of the sun's rays may be directed, in the leaf, to the *decomposition, not of carbonic acid, but of the water* of the sap. The oxygen of the water may be separated from the hydrogen, while at the same instant the latter element (hydrogen) may unite with the carbonic acid to produce the sugar or starch. The result here is the same as before, but the mode in which it is brought about is very differently represented and appears much more complicated. Thus suppose 24 of water (24 HO) to be decomposed, and to give off their oxygen into the air, 24 of oxygen would be evolved as in the former case, the whole of *which would be derived from the decomposition of water*, while there would remain

24 of HYDROGEN . . = H^{24} Let this act on
12 of CARBONIC ACID = $C^{12}\ O^{24}$, and we have

as the result . . . . . $O^{12}\ H^{24}\ O^{24}$; or

$$\underset{\text{Starch, \&c.}}{C^{12}\ H^{10}\ O^{10}} + \underset{\text{Water.}}{14\ HO.}$$

According to this mode of representing the chemical changes, water is first decomposed and its oxygen evolved, then its hydrogen again combines with the carbon and oxygen of the carbonic acid, forming two products—water and sugar or starch. This view is not only more complicated, but it supposes the same action of light to be—continually, at the same time, and in the same circumstances—both decomposing water and *re*-forming it from its elements. While, therefore, there can be no doubt, for other reasons, not necessary to be stated in this place, that the light of the sun really does decompose water in the leaves of plants, and more in some than in others—yet it appears probable that the oxygen evolved by the leaf is derived in a great measure from the carbonic acid which is absorbed; and that the principal part of the solid substance of living vegetables, in so far at least as it is derived from the air, is produced by the union of the carbon of this acid with the elements of the water in the sap.[*]

2°. We have seen reason to conclude (p. 87) that, while plants derive much of their sustenance from the air, they are also fed more or less abundantly by the soil in which they grow. From this soil they obtain through their roots the carbonic acid which is continually given off by the de-

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[*] I ought not to pass unnoticed the opinion of Persoz (*Chemie Moleculaire*), that the starch, gum, &c., of plants are formed by the union of *carbonic oxide* (CO) with the necessary proportions of oxygen and hydrogen derived from the water of the sap. This opinion implies that, in the leaf, carbonic acid (CO^2) is decomposed into carbonic oxide and oxygen ($CO + O$), and that water likewise is decomposed,—the oxygen produced by both decompositions being given off either into the air by the leaves, or into the soil by the roots. The production of grape sugar, therefore, according to this hypothesis, would be thus represented:—

		There are retained,	and given off
From 12 of CARBONIC ACID =	$12CO^2$	. . C^{12} O^{12}	. . . . O^{12}
From 12 of WATER . . . . . . =	$12HO$	. . H^{12}	. . . . O^{12}
		$C^{12}H^{12}O^{12}$ grape sugar	O^{24}

Of the 24 of oxygen thus given off, the opinion of Persoz is, that only one-half is evolved by the leaf,—and the principal fact on which his opinion rests is that observed by de Saussure, that plants of *Vinca minor* gave off by their leaves, in his experiments, only two-thirds of the oxygen contained in the carbonic acid they absorbed. This result has led Berzelius also to conjecture that the leaves of plants do not retain merely the carbon of the carbonic acid, but some compound of carbon with oxygen, containing much less of this element than the carbonic acid does (*Traité de Chemie*, V. p. 69). The principal objection to this view, however, is the quantity of oxygen it supposes to be rejected by the root. The experiments on which it is founded require confirmation and extension.

caying vegetable matter it contains. This carbonic acid will ascend to the leaf, and will there undergo decomposition along with that which is absorbed by the leaf itself. At least we know of no function of the root or stem by which the carbonic acid derived from the soil can be decomposed and deprived of its oxygen before it reaches the leaf.

It is distinctly stated, indeed, by Sprengel,* that when the roots of a plant are in the presence of carbonic acid, the oxygen given off by the leaf is greater in bulk than the carbonic acid absorbed. But there is one observation in connection with this point which it seems to me of importance to make. The leaves supply carbon to the plant only in the form of carbonic acid, and they give off a bulk of oxygen gas not exceeding† that of the acid taken in. But if the carbon derived from the soil be also absorbed in the form of carbonic acid, and if the oxygen contained in this portion of acid is also given off by the leaf—either the quantity drawn from the soil must be small, compared with that inhaled from the air, or the oxygen given off by the leaf must, in the ordinary course of vegetation, be sensibly greater than the bulk of the carbonic acid which it absorbs.

We are too little familiar with the chemical functions of the several parts of plants to be able to pronounce a decided opinion on this point; but it appears evident that one or other of the three following conditions must obtain:—

(*a*). Either in the general vegetation of the globe the bulk of the oxygen gas given off by the leaf during the day must always be considerably greater than that of the carbonic acid absorbed by it; or

(*b*). The root or stem must have the power of decomposing carbonic acid and of separating and setting free its oxygen; or

(*c*). The plant can derive no considerable portion of its carbon from the soil, in the form of carbonic acid.

If the experiments hitherto made by the vegetable physiologists be considered of so decisive a character as to warrant us in rejecting the two former conditions, the third becomes also untenable.

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* See above, p. 133.

† See note to p. 201.

3°. Without dwelling at present on this point, the above considerations may be regarded as giving additional strength or probability to the conclusions we formerly arrived at (p. 87) from other premises—that the roots, besides carbonic acid, absorb certain other soluble organic compounds, which are always present in the soil in greater or less quantity, and that the plant appropriates and converts these into its own substance. Some of these organic compounds may readily, and by apparently simple changes, be transformed into the starch and woody fibre of the living vegetable. The illustration of this fact will be reserved until, in the second part of these lectures, I come to treat of the vegetable portion of soils, and of the chemical nature and constitution of the organic compounds of which it consists, or to which it is capable of giving rise.

4°. The chemical changes above explained (*a*), show how from carbonic acid and the elements of water, substances possessed of the elementary constitution of sugar and gum may, by the natural processes of vegetable life, obtain the element of which they consist, and in the requisite proportions. They throw no light, however, upon the mechanism by which these elements are constrained, as it were, to assume *first* the form of gum or sugar, or soluble starch, and *afterwards*, in another part of the plant, of insoluble starch and woody fibre.

It is known that the sap deposits starch and woody fibre in the stem, only in its descent from the leaf,—and it is, therefore, inferred that the action of light upon the sap, as it passes through the green parts, is necessary to dispose the elements to arrange themselves in the form of vascular fibre or lignin. And as, by the agency of nitric acid, starch appears to be convertible into woody fibre (p. 186), it is not unlikely that the soluble substances, containing nitrogen, which are present in the sap may—as diastase does upon starch—exercise an agency in transforming the soluble sugar, gum, &c., of the sap into the insoluble starch and woody fibre of the seed and the stem. We are here, however, upon uncertain ground, and I refrain from advancing any further conjectures.

Two great steps we have now made. We have seen how the germ lives and grows at the expense of the food stored up in the seed—and how, when it has obtained roots and leaves, the plant is enabled to extract from the air and from the soil such materials as, in kind and quantity, are fitted to build up its several parts during its future growth. That considerable obscurity still rests on the details of what takes place in the interior of the plant, does not detract from the value of what we have already been able to ascertain.

§ 3. *On the production of oxalic acid in the leaves and stems of plants.*

In the preceding section we have studied the origin of those substances only which form the chief bulk of the products of vegetation, and which are characterized by a chemical constitution of such a kind as enables them to be represented by carbon and water. But during the stage of vegetable growth we are now considering, other compounds totally different in their nature are also produced, and in some plants in sufficient quantity to be deserving of a separate consideration. Such is the case with oxalic acid.

The circumstances under which this acid occurs in nature have already been detailed. It is found in small quantities in many plants. The potash in forest trees is supposed to be in combination with oxalic acid, while in the lichens *oxalate of lime* serves a purpose similar to that performed by the woody fibre of the more perfect plant; it forms the skeleton by which the vegetable structure is supported, and through which its vascular system is diffused.

The production of this acid in the living plant is readily understood when its chemical constitution (C^2O^3) is compared with that of carbonic acid (CO^2). For

$$\begin{array}{lr} \text{2 of CARBONIC ACID} = & C^2O^4 \\ \text{1 of OXALIC ACID} \; . = & C^2O^3 \\ \hline \text{Difference} \; . \; . & O^1 \end{array}$$

That is to say, 2 of carbonic acid are transformed into

1 of oxalic acid by the loss of 1 equivalent of oxygen—or generally, *carbonic acid by the loss of one-fourth of its oxygen may be converted into oxalic acid.*

But the leaf absorbs carbonic acid and gives off oxygen. In the lichens, therefore, which contain so much oxalic acid, a large portion of the carbonic acid absorbed is, by the action of light, deprived of only one-fourth of its oxygen, and is thus changed into oxalic acid. The same is true to a smaller extent of the sorrel leaves and stems, which owe their sourness to the presence of oxalic acid—of the leaves and stems of rhubarb also—in a still smaller degree of the beech and other large trees, in which much potash, and probably, also, of marine plants, in which much soda is found to exist. It must be owing to the peculiar structure of the leaves of each genus or natural order of plants, that the same action of the same light decomposes the carbonic acid in different degrees—evolving in some a less proportion of its oxygen, and causing in such plants the formation of a larger quantity of oxalic acid.

The fact of the production of this oxalic acid, to a very considerable amount in many plants, is a further proof of the uncertainty of those experiments from which physiologists have concluded that the leaves of plants emit a bulk of oxygen sensibly equal to that of the carbonic acid absorbed.*

I have referred the production of more or less oxalic acid in different plants to the special structure of each, and this must be true, where, in the same circumstances, different results of this kind are observed to take place—as where sorrels and sweet clovers grow side by side. Yet the influence of light of different degrees of intensity on the same plant is beautifully shown by the leaves of the *Sempervivum arboreum*, of the *Portulacaria afra*, and other plants *which are sour in the morning, tasteless in the middle of the day, and bitter in the evening.*[*] During the night the oxygen has accumulated in these plants and formed acids containing oxygen in excess (p. 187.) As the day advances this oxygen is given off; under the influence of light the acids are decomposed, and the sourness disappears.

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* Were we permitted, in the absence of decisive experiments, to state as true what theoretical considerations plainly indicate, we should say—

1°. That plants containing much oxalic or other similar acids, and not deriving much carbonic acid from the soil, must give off from their leaves a bulk of oxygen *less* than that of the carbonic acid absorbed.

2°. That plants containing no sensible quantity of such acids, nor fed by carbonic acid from the soil, may evolve oxygen sensibly *equal* in bulk to the carbonic acid absorbed.

3°. That if little of these acids be present, and much carbonic acid be absorbed from the soil, the volume of oxygen given off by the green parts of the plant must be sensibly *greater* than that of the carbonic acid they absorb.

4°. That the leaves of the pines and other trees containing much turpentine—in which hydrogen is in excess—must at all times give off oxygen in *greater* bulk than the carbonic acid they absorb. They must decompose water as well as carbonic acid, and evolve the oxygen of both.

In the juices of plants before the period of flowering, other acids also are met with besides the oxalic acid, though in much smaller quantity. As the most important of these, however, occur more abundantly in fruits, we shall consider the theory of their formation in the following section.

§ 4. *Of the chemical changes which take place between the opening of the flower and the ripening of the fruit or seed.*

The opening of the flower is the first and most striking step taken by the plant towards the production of the seed by which its species is to be perpetuated. That at this period a new series of chemical changes commences in the plant is obvious from the following facts :—

1°. That the flower leaves absorb oxygen and emit carbonic acid both by day[†] and by night (p. 137.)

2°. That they also occasionally emit pure nitrogen gas.

3°. That the juice of the maple ceases to be sweet when the flowers are matured (Liebig,) and that, in the sugar cane and beet root, the sugar becomes less abundant when the plant has begun to blossom.

These facts sufficiently indicate the commencement of new changes in the interior of plants at this period of their growth. That such changes go on until the ripening of the seed is also evident from these further observations :

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[*] Sprengel, *Chemie*, II., p. 321.

[†] By day the absorption is the greater, but the bulk of the oxygen taken in is always greater than that of the carbonic acid given off.

1°. That the husk of the future seed, as in the corn-bearing grasses (wheat, oats, &c.,) is filled at first with a milky liquid, which becomes gradually sweeter and more dense, and finally consolidates into a mixture of starch and gluten, such as is presented by the flour of different species of corn.

2°. That the fruit in which the seeds of many plants is enveloped is at first tasteless, afterwards more or less sour, and finally sweet. In a few fruits only, as in the lime, the lemon, and the tamarind, does a sufficient quantity of acid remain to be sensible to the taste, when the seed has become perfectly ripe. The acid and cellular fibre both diminish while the sugar increases.

3°. That fruits, while green, act upon the air like the green leaves and twigs—but that, as they approach maturity, they also absorb or retain oxygen gas (De Saussure.) The same absorption of oxygen takes place when unripe fruits are plucked and left to ripen in the air (Berard.) After a time the latter also emit carbonic acid.

I.—FORMATION OF THE SEED.

In the case of wheat, barley, or other plants, which yield farinaceous seeds, we have seen that previous to flowering the chief energy of the living plant is expended in the production of the woody fibre of which its stem and growing branches mainly consist; and we have also been able to understand, in some degree, how this woody fibre is produced from the ordinary food of the plant. When the flower expands, however, the plant has in general, and especially if an annual plant, reached nearly to maturity, and woody fibre is little required. The most important of its remaining functions is the production of the starch and gluten of the seed, and of the substances which form the husk by which the seed is enveloped.

In the first stages of the plant's growth, the starch of the seed is transformed into gum and sugar, and subsequently, when the leaves are expanded, into woody fibre. In the last stages of its existence, when it is producing the seed, the sugar of the sweet and milky sap is gradually transformed into starch—that is to say, a process exactly the converse of the former takes place.

We are able, in some measure, to explain the mode and agency by which the former transformation is effected—the latter, however, is still inexplicable. We can ourselves, by the agency of diastase, transform starch into sugar; and therefore, can readily believe such transformations to be effected in the young plant;—but we as yet know no method of *re*-converting sugar into starch; and, therefore, we can only hazard conjectures as to the way in which this change is brought about in the interior of the plant during the formation of the seed.

It is said that nitrogen is given off by the flower leaf. We know that this element is present in the colouring matter of the petal, and that is a necessary constituent of the albumen and gluten, which are always associated with the starch of the seed. It is plain, then, that the nitrogeneous* substances contained in the sap at all periods of the plant's growth are carried up in great quantity to the flower and seed vessel. These substances are *supposed* to be concerned as immediate agents in effecting the transformations which there take place. More than this, however, we cannot as yet venture even to conjecture.

II.—RIPENING OF THE FRUIT.

In those plants again, which invest their seed with a pulpy fruit—in the grape, the lemon, the apple, the plum, &c.—other changes take place, at this period, of a more intelligible kind, and other substances are formed, on the production of which less obscurity rests. At one stage of their growth these fruits, as has been already stated, are tasteless—in the next, they are sour—in the third, they are more or less entirely sweet.

1°. In the tasteless state they consist of little more than the substance of the leaf—of vascular, or woody fibre, filled with a tasteless sap, and tinged with the colouring matter of the green parts of the plant. For a time, this young fruit appears to perform in reference to the atmosphere the usual functions of the leaf—it absorbs carbonic acid and gives off oxygen, and thus extracts from the air a portion of the food by which its growth is promoted, and its size gradually increased.

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* Substances containing nitrogen.

II°. But after a time this fruit becomes sour to the taste, and its acidity gradually increases—while at the same time it is observed to give off a less comparative bulk of oxygen than before. Let us consider shortly the theory of the production of the more abundant vegetable acids contained in fruits.

1°. The *tartaric acid* which occurs in the grape is represented by $C^4 H^2 O^5$ (p. 182).

There are two ways in which we may suppose this acid to be formed in the fruit—either directly from the elements of carbonic acid and water with the *evolution* of oxygen gas—or from the gum and sugar already present in the sap aided by the *absorption* of oxygen from the atmosphere. Thus

A. 4 of CARBONIC ACID = $C^4 \quad O^8$
2 of WATER . . = $H^2 O^2$

Tartaric acid.

Sum . . = $C^4 H^2 O^{10}$ or $C^4 H^2 O^5 + 5O$

That is, one equivalent of tartaric acid may be formed from 4 of carbonic acid absorbed by the leaf or fruit, and 2 of the water of the sap, while 5 of oxygen are at the same time given off by the leaf. Or,

B. If Grape-Sugar be $C^{12} H^{12} O^{12}$
$\frac{1}{3}$ of GRAPE SUGAR = $C^4 H^3 O^3$
3 of OXYGEN . . = O^3

Sum . . = $C^4 H^3 O^6$

Tartaric Acid. Water.
or $C^4 H^2 O^5 + H O$,

That is, by the absorption from the air of a quantity of oxygen equal to that which it already contains, grape-sugar may be converted into tartaric acid and water.

In the sorrels and other sour leaved plants, which contain tartaric acid in their general sap, the acid may be formed by either of the processes above explained. In the sunshine their green parts absorb carbonic acid and evolve oxygen. If any of these green parts give off only ^{3} of the oxygen contained in the carbonic acid they drink in, tartaric acid may be produced (A.) In the dark they absorb oxygen and give off carbonic acid. If the bulk of this latter gas which escapes be less than that of the oxygen which enters, a portion of the sugar or gum of the sap may, as above explained (B.), be converted into tartaric acid.

We have as yet no experiments which enable us to say by which of these modes the tartaric acid is really produced in such plants—or whether it may not occasionally be compounded by both methods.

In green fruits also, in the sour grape for example, it may, in like manner, be produced by either method. The only experiments we yet possess, those of De Saussure, though not sufficient to decide the point, are in favour of the former explanation (A.) In the estimation of this philosopher, the proportion of the oxygen of the carbonic acid which is retained by the fruit, is sufficient to account for the acidity it gradually acquires.

2°. *Malic and citric acids.* These acids are represented (p. 187) by the common formulæ $C^4 H^2 O^4$. They may be be produced from water and carbonic acid, if three-fourths only of the oxygen of the latter be given off. Thus

$$\begin{array}{llll}
4 \text{ of } \textsc{Carbonic Acid} & = & C^4 & O^8 \\
2 \text{ of } \textsc{Water} \;.\;.\;. & = & & H^2 O^2 \\
\hline
\text{Sum} \;.\;. & = & C^4 H^2 O^{10} = \overset{\text{Malic Acid.}}{\underbrace{C^4 H^2 O^4}} + 6\,O &
\end{array}$$

That such a retention of one-fourth of the oxygen of the carbonic acid occasionally takes place in the green fruit, is consistent with the observations of De Saussure. The lime and the lemon are fruits on which the most satisfactory experiments might be made with the view of finally determining this point.

III°. This formation of acids proceeds for a certain time, the fruit becoming sourer and sourer; the acidity then begins to diminish, sugar is formed, and the fruit ripens. The acid rarely disappears entirely, even from the sweetest fruits, until they begin to decay; a considerable portion of it, however, must be converted into grape-sugar, as the fruit approaches to maturity. This conversion may take place in either of two ways.

1°. By the direct evolution of the excess of oxygen. Thus

$$\begin{array}{lcl}
\text{3 of Tartaric Acid} & = & C^{12}\,H^{6}\,O^{15} \\
\text{6 of Water} \;\ldots & = & \underline{\quad\;\; H^{6}\,O^{6}} \\
\text{Sum} \;\ldots & = & C^{12}\,H^{12}\,O^{21} = \underbrace{\overset{\text{Grape sugar.}}{C^{12}\,H^{12}\,O^{12}}} + 9O
\end{array}$$

Or grape-sugar may be formed from 3 of tartaric acid and 6 of the water of the sap, by the evolution, at the same time, of 9 of oxygen. Citric and malic acids, in the same proportion, would form grape-sugar by the evolution of 6 of oxygen only.

Do fruits, when they have reached their sourest state, begin thus to give off an excess of oxygen? I know of no experiments which as yet decide the point.

2°. By the absorption of oxygen and the evolution of carbonic acid. Thus, in the case of tartaric acid,

$$\begin{array}{lcl}
\text{1 of Tartaric Acid} & = & C^{4}\,H^{2}\,O^{5} \\
\text{1 of Oxygen} \;\ldots\ldots & = & \underline{\qquad\quad O^{1}} \\
\text{Sum} \;\ldots & = & C^{4}\,H^{2}\,O^{6} = \overset{\text{1-6th of Grape Sugar.}}{C^{2}\,H^{2}\,O^{2}} + 2\;\overset{\text{Carbonic Acid.}}{CO^{2}}
\end{array}$$

Where one of oxygen is absorbed and 2 of carbonic acid given off. Or in the case of the malic and citric acids,

$$\begin{array}{lcl}
\text{1 of Malic Acid} & = & C^{4}\,H^{2}\,O^{4} \\
\text{2 of Oxygen} \;\ldots & = & \underline{\qquad\quad O^{2}} \\
\text{Sum} \;:\,. & = & C^{4}\,H^{2}\,O^{6} = \overset{\text{1-6th of Grape Sugar.}}{C^{2}\,H^{2}\,O^{2}} + 2\;\overset{\text{Carbonic Acid.}}{CO^{2}}
\end{array}$$

Where 2 of oxygen are absorbed and 2 of carbonic acid given off.

We know from the experiments of Berard that, when unripe fruits are plucked, they do not ripen if excluded from the access of oxygen gas—but that in the air they ripen, absorbing oxygen at the same time, and giving off carbonic acid. This second method (2°) therefore exhibits the more probable theory of the ripening of fruits *after they are plucked*; and if—*as they become coloured*—fruits imitate the petals of the flower in absorbing oxygen from the air and giving off carbonic acid, it will also represent the changes which take place when they are permitted to ripen on the tree.

During the ripening of the fruit, it has been stated that the woody or cellular fibre it contains gradually diminishes, and is converted into sugar. This is familiarly noticed in some species of hard or winter pears. In sour fruit, the cellular fibre seldom exceeds 2½ per cent. of their whole weight;—in ripe fruits, however, it is still less, and as the constitution of this substance is so analogous to that of grape-sugar, there is no difficulty in understanding that it may be readily converted into the latter, through the immediate agency by which the transformation is effected is as yet unknown to us.

§ 5. *Of the chemical changes which take place after the ripening of the fruit and seed.*

When the seed is fully ripe, the functions of annual plants are discharged. They no longer require to absorb and decompose carbonic acid, for their growth is at an end. Their leaves begin, therefore, to take in oxygen only, become yellow, and prepare along with the entire plant, for being finally resolved again into those more elementary substances from which they were originally compounded.

On trees and perennial plants however, a further labour is imposed. In the ripened seed they have deposited a supply of food sufficient to sustain the germ that may spring from it, until it is able to seek food for itself; but the young buds already formed,—and which are to shoot out from the stem and branches in the ensuing spring,—are in reality so many young plants for which a store of food has yet to be laid up in the inner bark, and in the wood of the tree or shrub itself.

In the autumn, the sap of trees and permanent shrubs continues to flow rapidly till the leaf withers and falls, and the food of the plant is converted partly into woody fibre, as was the case during the earlier period of the year, and partly into starch. The former is deposited beneath the inner bark to form the new layer of wood by which the tree is annually enlarged; the latter—partly in the same locality as in the birch and pine—partly throughout the substance of the wood itself, as in the willow—while in the palm trees and cycadeæ, it is intermingled with the central pith. The chemical changes by which the food is capable of being converted into these substances have already been considered. They proceed during the entire autumn, do not cease so long as the sap continues to move, and even in the depth of winter slowly and silently operate in storing up farinaceous matter—in readiness, like the starch in the seed, to minister to the nourishment of the young bud, when the warmth of the coming spring shall awaken it from its long sleep.

§ 6. *Of the rapidity with which these changes take place, and the circumstances by which they are promoted.*

But remarkable as those chemical changes are, the rapidity with which they sometimes take place is no less surprising.

From carbonic acid and water we have seen that the plant by very intelligible processes, can extract the elements of which its most bulky parts consist—and can build them up in many varied ways, most of which are probably beyond the reach of imitation. But who can understand or explain the extraordinary activity which pervades the entire vascular system of the plant, when circumstances are favourable to its growth?

A stalk of wheat has been observed to shoot up three inches in as many days, of barley six inches in the same time, and a vine twig almost two feet, or eight inches a day (Du Hamel). Cucumbers have been known to acquire a length of twenty-four inches in six days, and in the Botanic Garden at Brussels I was shown a bamboo five inches in diameter, which had increased in height nine feet in twenty-seven days, sometimes making a progress of six to eight inches in a day. In our climate we meet with few illustrations of the rapidity with which plants are capable of springing up in the most favourable circumstances, and the above examples probably give us only an imperfect idea of the velocity with which the bamboo, the palm, the tree fern, and other vascular plants, may grow in their native soil and climate. And with what numerous and complicated chemical changes is the production of every grain of the substance of these plants attended—how rapidly must the food be selected and absorbed from the air and from the soil—how quickly transformed and assimilated!

The long period of time during which, year after year, these changes may proceed in the same living vessels, or in the same tree, is no less wonderful. Oaks have lived to an age of 1500 or 2000 years—Yew trees to 3000 years—and other species are mentioned as having flourished from 4500 to 6000 years; while even a living rose tree (*rosa canina*) is quoted by Sprengel as being already upwards of 1000 years old.*

The rapidity of the growth of a plant, and the length of its life, are equally affected by circumstances. On a knowledge of these circumstances, and of the means of controlling or of producing them, the enlightened practice of agriculture is almost entirely dependent.

Over the *natural* conditions on which vegetation in general depends, we can exercise little control. By hedge-rows and plantations we can shelter exposed lands, but, except in our conservatories and hot-houses, the plants we can expect to cultivate with profit will always be determined by the general climate in which we live. So the distribution of rain and sunshine are beyond our control, and though it is ascertained that a thundery condition of the atmosphere is remarkably favourable to vegetable growth,† we cannot hope that such a state of the air will ever be induced, at the pleasure or by the agency of man. But under the same *natural* conditions of climate, there are many *artificial* methods by the use of which it is within our power to accelerate the growth, and to increase the produce of the most valuable objects of ordinary culture.

Thus the germination of seeds in general is hastened by watering with a solution of chlorine (Davy), or of iodine or bromine (Blengini), and Davy found that radish seed which germinated in two days when watered with solutions of chlorine or sulphate of iron, required three when watered with very dilute nitric acid, and five with a weak solution of sulphuric acid.

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* Sprengel, *Lehre vom Dünger*, p. 76.

† *Ibid*, p. 73.

It is familiarly known also in ordinary husbandry, that the application of manures hastens in a similar degree the development of all the parts of plants during every period of their growth—and largely increases the return of seed obtained from the cultivated grains. Ammonia and its compounds likewise, and nitric acid and its compounds, with many other saline substances existing in the mineral kingdom and occurring in soils, or which are produced largely in our manufactories, have been found to produce similar effects.

It would be out of place here to enter upon the important and interesting field opened up to us by a consideration of the influence exercised by these and other substances, in modifying both in kind and in degree the chemical changes which take place in living vegetables. The true mode of action of such substances—their precise effects—the circumstances under which these effects are most certainly produced—and the theoretical views on which they can be best accounted for—will form a subject of special and detailed examination in the third part of the present lectures.

LECTURE VIII.

How the supply of food for plants is kept up in the general vegetation of the globe. Proportion of their food drawn by plants from the air. Supply of carbonic acid. Supply of ammonia and nitric acid. Production of both in nature. Theory of their action on living vegetables. Concluding observations.

Having shown in the preceding Lecture in what way, and by what chemical changes, the substances of which plants chiefly consist may be produced from those on which they live,—there remains only one further subject of inquiry in connection with the organic constituents of plants.

Plants, as we have already seen, derive much of their sustenance from the carbonic acid of the atmosphere; yet of this gas the air contains only a very small fraction, and in so far as experiments have yet gone, this fractional quantity does not appear to diminish—how, then, is the supply of carbonic acid kept up?

Again, plants most probably obtain much of their nitrogen either from ammonia or from nitric acid; and yet, neither in the soil nor in the air do these compounds permanently exist in any notable quantity,—whence then is the supply of these substances brought within the reach of plants?

The importance of these two questions will appear more distinctly, if we endeavour to estimate how much of their carbon plants really draw from the atmosphere—and how much of the nitrogen they contain must be derived from sources not hitherto pointed out.

§ 1. *Of the proportion of their carbon which plants derive from the atmosphere.*

On this subject it is perhaps impossible to obtain perfectly accurate results. Several series of experiments, however, have been published, which enable us to arrive at very useful approximations in regard to the proportion of their carbon which plants, growing in a soil of ordinary fertility, and in such a climate as that of Great Britain, actually extract from the air by which they are surrounded.

1°. In an experiment made in 1824, upon common borage (Borago officinalis), Lampadius found that after a growth of five months (from the 3rd of April to the 6th of September) this plant produced ten times as much vegetable matter as the soil in which it grew had lost during the same period.* In other words, *it had drawn nine-tenths of its carbon from the air.*

2°. The experiments of Boussingault were made if not with more care, at least upon a greater number of plants, and were protracted through a much longer period. It is necessary that we should understand the principle on which they were conducted, in order that we may be prepared to place confidence in the determinations at which he arrived.

If we were to examine the soil of a field on which we are about to raise a crop of corn—and should find it to contain a certain per centage, say 10 per cent. of vegetable matter (or 5 per cent. of carbon);—and after the crop is raised and reaped should, on a second examination, find it to contain exactly the same quantity of carbon as before, we could not resist the conviction, that, with the exception of what was originally in the seed, the plant during its growth had drawn from the air all the carbon it contained. The soil *having lost none, the air must have yielded the whole supply.*

Or if after examining the soil of our field we mix with it a supply of farm-yard manure, containing a known weight, say one ton of carbon, and when the crop is reaped find as before that the per-centage of vegetable matter in the soil has suffered no diminution,† we are justified in concluding that the crop cannot, at the utmost, have derived from the soil any greater weight of its carbon than the ton contained in the manure which had been added to it.

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* The above experiment may have been correctly made, but the result appears at first sight too startling to be readily received as indicative of the proportion of their sustenance drawn by plants from the air *in the general vegetation of the globe.*

† I need scarcely remark that, in the hands of a good farmer, who

Such was the principle on which Boussingault's experiments were conducted. He determined the per-centage of carbon in the soil before the experiment was begun—the weight added in the form of manure—the quantity contained in the series of crops raised during an entire rotation or course of cropping, until in the mode of culture adopted it was usual to add manure again—and lastly, the proportion of carbon remaining in the soil. By this method he obtained the following results in pounds per English acre, in three different courses of cropping, and on the same land:—

	Carbon in the Manure.	Carbon in the Crops.	Difference, or Carbon derived from the air.	REMARKS.
First Course	2513	7544	5031	The first was a 5 years' course—of potatoes or red beet with manure, wheat, clover, wheat, oats; the second and most productive rotation was abandoned on account of the climate; the third was a 3 years course.
Second do.			6839	
Third do.			3921	

The result of the first course indicates that—the land remaining in equal condition at the end of the four years as it was at the beginning—the crops collected during these years contained three times the quantity of carbon present in the manure, and *therefore the plants, during their growth, must on the whole have derived two-thirds of their carbon from the air.*

It will be shown in a subsequent section that even when the soil is lying naked the animal and vegetable matter it contains is continually undergoing diminution, owing to decomposition and the escape of volatile substances into the

keeps his land in *good heart*—the quantity of organic matter in the soil at the end of his course of cropping should be as great, at least, as it was at the beginning of his rotation, before the addition of the manure.

air. It is fair, therefore, to assume that a considerable portion of the carbon of the manure and of the soil would naturally disappear during the four years' cropping abovementioned, and that, therefore, the proportion of carbon derived from the air in Boussingault's experiments, must have been really considerably greater than is indicated by the numerical results.

Let two-thirds of the entire quantity of carbon contained in a series of crops be taken as the average* proportion which, on cultivated land in our climate, must be derived from the air in the form of carbonic acid—and let the average weight of the dry crop reaped be estimated at a ton and a half per acre. Then, if the crop contain half its weight of carbon,† the plants grown on each acre must annually extract from the air 10 cwt. or 1120 lbs. of carbon in the form of corbonic acid.

§ 2. *Of the relation which the quantity of carbon extracted by plants from the air, bears to the whole quantity contained in the atmosphere.*

But the question will here at once suggest itself to you—does not the quantity thus extracted from the air really form a very large proportion of the whole weight of carbon which is contained in the atmosphere? A simple calculation will give us clear ideas in regard to this interesting point.

We have already seen that by the results of De Saussure, the average quantity of carbonic acid in the atmosphere of our globe may be estimated at $\frac{1}{2500}$ part of its entire bulk. This is equal very nearly to $\frac{3}{5000}$ of its weight.‡ Or taking

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[*] Lecture II., p. 35.

[†] Boussingault states, that of all the plants usually cultivated for food—so far as his experiments have gone—the Jerusalem artichoke draws the largest portion of its sustenance from the air—or *yields the greatest weight of food from the smallest weight of manure* It is true generally indeed that all those plants, which, like the Jerusalem artichoke and the white carrot, grow freely on sandy soils containing little vegetable matter and with the addition of little manure, extract the greatest proportion of their sustenance from the air. Such plants, therefore, are likely to prove the most profitable articles of culture where such soils and a scarcity of manure simultaneously prevail.

[‡] The mean of 225 experiments made by De Saussure between 1827

the whole weight of the atmosphere at 15 lbs. on the square inch—that the carbonic acid will be 0.009 lbs., or 63 grs. per square inch. But as carbonic acid contains only 27$\frac{2}{3}$ per cent. of its weight of carbon, the weight of this element which presses on each square inch of the earth's surface is only 17$\frac{2}{5}$ (17·39) grs. Upon an acre this amounts to 7 tons.*

But if the crop on each acre of cultivated land annually extracts from the air half a ton of carbon, the whole of the carbonic acid in the atmosphere would sustain such a vegetation over the entire globe for 14 years only. And if we even suppose such a vegetation to extend over one hundredth part of the earth's surface only, it still appears sufficient to exhaust the carbonic acid of the air in 1400 years.

A very short period, compared even with the limits of authentic history, has yet elapsed since experiments began to be made on the true constitution of the atmosphere; we have no very trustworthy data, therefore, on which to found a confident opinion in regard to the permanence of the proportion of carbonic acid which it now contains. The later observations of De Saussure do give a considerably lower estimate of the quantity of this acid in the air than that which was deduced from the results of the earlier experimenters but the imperfection of the modes of analysis formerly adopted was too great, to justify us in reasoning rigorously from the inferences to which they lead. We cannot

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and 1829 gave as above stated about 4-10000 or 1-2500th part for the mean bulk of the carbonic acid in the air, which is nearly 6-1000ths of its whole weight. Among these observations the maximum was 5·8 ten thousandths, the minimum 3·15. If we take the maximum *bulk* at 6-10000ths of the air—the maximum *weight* of the carbonic acid is nearly 9-10000ths of that of the atmosphere. In elementary works it is generally stated in round numbers at 1-1000th of the weight of the air, but if the best experimental results we possess are to be any guide to us, this is at least one-third too high.

It is also of consequence to remark, that this estimate of the whole weight of the carbonic acid in the air is founded on the supposition that, in the highest regions of the atmosphere, the cabonic acid is present in a proportion nearly equal to that in which it is found immediately above the earth's surface—which is by no means established.

* 15,583 lbs.—an acre being 4840 square yards, containing each 1296 square inches.

safely conclude from them that the proportion of carbon in the atmosphere has really diminished to any sensible extent during this limited period; while the recorded identity of all the phenomena of vegetation render it probable that the proportion has not sensibly diminished even within historic times.

From what sources, then, is the supply of carbonic acid in the atmosphere kept up?—and if the proportion be permanent, by what compensating processes is the quantity which is restored to the atmosphere produced and regulated?

§ 3. *How the supply of carbonic acid in the atmosphere is renewed and regulated.*

On comparing, in a previous lecture, the quantity of rain which falls with that of the watery vapour actually present in the air, we saw reason to believe that even in a single year the same portion of water may fall in rain or dew and ascend again in watery vapour several successive times. Is it so also with the carbon in the air? Does that which feeds the growing plant to-day, again mount up in the form of carbonic acid at some future time, ready to minister to the sustenance of new races, and to run again the same round of ever-varying change? Such is, indeed, the *general* history of the agency of the carbonic acid of the atmosphere; but when once it has been fixed in the plant it must pass through many successive changes before it is again set free. The conditions, also, under which it is restored to the atmosphere are so diversified—and the agencies by which, in each case, it is liberated are so very distinct, as to require that the several modes by which the carbon of plants is reconverted into carbonic acid and returned to the air, should be made topics of separate consideration.

I.—ON THE PRODUCTION OF CARBONIC ACID BY RESPIRATION.

The air we breathe when it is drawn *into* the lungs, contains $\frac{1}{2500}$th of its bulk of carbonic acid; when it returns again *from* the lungs, the bulk of this gas amounts, on an average,* to $\frac{1}{25}$th of the whole; or *its quantity is increased one hundred times.*

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* It varies in different individuals from 2 to 8 per cent. of the expired

The actual bulk of the carbonic acid emitted from the lungs of a single individual in 24 hours varies exceedingly; it has been estimated, however, on an average, to contain upwards of five ounces of carbon.* A full grown man, therefore, gives off from his lungs, in the course of a year, upwards of 100 lbs. of carbon in the form of carbonic acid.

If the quantity of carbon thus evolved from the lungs be in proportion to the weight of the animal, a cow or a horse ought to give off six times as much as a man.† From indirect experiments, however, Boussingault‡ estimated the quantity of carbon actually lost in this way by a cow at 2200 grammes in 24 hours, and by a horse at 2400 grammes. These quantities are equal to 6 or 7 times the amount of carbon given off from the lungs of a man.

If we suppose each inhabitant of Great Britain, young and old, to repire only 80 lbs. of carbon in a year, the twenty millions would emit seven hundred thousand tons; and, allowing the cattle, sheep, and all other animals, to give off twice as much more, the whole weight of carbon returned to the air by respiration in this island would be about two millions of tons, or the quantity abstracted from the atmosphere by four millions of acres of cultivated land.

Whence is all this carbon derived? It is a portion of that which has been conveyed into the stomach in the form of food. Suppose the carbon contained in the daily food of a full grown man to amount to one pound—which is a large allowance—then it appears that, by the ordinary processes of respiration, *at least one-third of the carbon of his food is daily returned into the air.*

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air. In animals it varies also with the species. The air from the lungs of a cat contains from 5½ to 7 per cent., of a dog from 4½ to 6½, of a rabbit from 4 to 6, and of a pigeon from 3 to 4 per cent. of the whole bulk.—Dulong, *Annal. de Chim. et de Phys., third Series, I.*, 455.

[*] Davy, and Allen and Pepys, estimated the weight of carbon evolved in a day at upwards of 11 ounces, a quantity which all writers have concurred in receiving with suspicion.

[†] Estimating the ordinary weight of a man at 150, and of a cow at 800 to 900 lbs.—See Sprengel, *Lehre vom Dünger*, p. 208.

[‡] *Ann. de Chim. et de Phys.* lxxi., pp. 127 and 136.

In other animals the proportion returned may be different from what it is in man, yet the life of all depends on the emission to a certain extent of the same gas.* And since all are sustained by the produce of the soil, it is obvious that the process of animal respiration is one of those methods, by which it has been provided that a large portion of the vegetable productions of the globe should be almost immediately resolved into the simpler forms of matter from which it was originally compounded, and again sent up into the air to minister to the wants of new races.

II.—ON THE PRODUCTION OF CARBONIC ACID BY COMBUSTION.

Another important source of carbonic acid is familiar to us in the results of artificial combustion.

In the previous lecture I have shown how, by the action of the sun's rays upon the leaf, the carbonic acid absorbed from the atmosphere is deprived of its oxygen, and its carbon afterwards united to the elements of water for the production of woody fibre. During the process of combustion, this labour of the living leaf is undone—the carbon is made to combine anew with the oxygen of the atmosphere, and the vegetable matter is resolved again into carbonic acid and water.

Thus, when wood (woody fibre) is burned in the air, oxygen disappears, and carbonic acid and watery vapour are alone produced. The theory of this change is simple.

It will be recollected (p. 200) that in forming an equivalent of woody fibre or of sugar, 24 of oxygen were given off, chiefly by the leaf—so in again resolving these substances into carbonic acid and water, 24 of oxygen are absorbed. Thus—

1 of Woody Fibre = $C^{12}H^{8}O^{8}$
24 of Oxygen . = O^{24}
12 of Carbonic acid. 8 of Water.
Sum . = $C^{12}H^{8}O^{32} = 12CO^{2} + 8HO$

Or, 1 of Cane Sugar = $C^{12}H^{10}O^{10}$,
24 of Oxygen . = O^{24}
12 of Carbonic acid. 10 of Water.
Sum . = $C^{12}H^{10}O^{34} = 12CO^{2} + 10HO$

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* That the proportion *must* be less in the larger animals is certain

The same law holds in regard to all other vegetable substances. They are resolved into carbonic acid and water, in proportions which necessarily vary with the chemical constitution of each.

It applies also to all bodies of vegetable *origin*, among which nearly all combustible minerals may be reckoned. The peat and coal we burn in our houses and manufactories, when supplied with a sufficiency of atmospheric air, are resolved during cumbustion into carbonic acid and watery vapour.

Some vegetable substances contain a small quantity of nitrogen. When these are burned, this nitrogen escapes into the atmosphere,—generally in an uncombined state,—and mingles with the air. So in animal substances, nearly all of which contain nitrogen as an essential constituent. During perfect combustion the whole of the carbon is dissipated in the form of carbonic acid while the nitrogen rises along with it in an elementary state.

The result of this uniform subjection of all combustible matter to the operation of this one law, is the constant production on the surface of the globe of a vast quantity of carbonic acid;—the *re*-conversion of large masses of organic matter into the more elementary compounds from which it was originally formed.

How interesting it is to contemplate the relations, at once wise and beautiful, by which through the operation of such laws, dead organic matter, intelligent man, and living plants, are all bound together! The dead tree and the fossil coal lie almost useless things in reference to animal and vegetable life,—man employs them in a thousand ways as ministers to his wants, his comforts, or his dominion over nature—and in so doing, himself directly though unconsciously ministers to the wants of those vegetable races, which seem but to live and grow for his use and sustenance.

It is impossible to say what proportion of the carbon ab-

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since the daily food of a cow may be stated generally as equivalent to 25 lbs. of hay, containing upwards of 10 lbs. of carbon. If one-third of this were given off from the lungs, the quantity of carbon (3⅓ lbs.) evolved would be ten times greater than was indicated by the experiments of Boussingault, and nearly double of what the weight of a cow, compared with that of a man, requires.

sorbed during the general vegetation of the globe, is thus annually restored to the atmosphere by the burning of vegetable matter. That it must be very great, will appear from the single fact, that by far the greater part of the globe is dependent for its supply of fuel on the animal produce of its forests;—while even in those more favoured countries where mineral coal abounds, the quantity of wood consumed by burning falls but little short of the entire yearly growth of the land.

In connection with this subject, I must draw your attention to one interesting, as well as important, fact. I have spoken of coal as a substance of vegetable origin, and there is no doubt that all the carbon it contains once floated in the air in the form of carbonic acid. But the period when it was so mixed with the atmosphere, is remote almost beyond conception. When, therefore, we raise coal from its ancient bed and burn it on the earth's surface, *we add to the carbon of the air a portion which has not previously existed in the atmosphere of our time.*

The coal consumed in Great Britain alone is estimated at 20 millions of tons, containing on an average at least 70 per cent., or 14 millions of tons of carbon. But if the annual produce of an acre of cultivated land contain half a ton (p. 219) of carbon derived from the air, the coal consumed in this country would supply carbonic acid to the crops grown upon 28 millions of acres. Or, since in Great Britain about 34 millions of acres are in cultivation (p. 4), *the coal we annually consume produces a quantity of carbonic acid which is alone sufficient to supply food to the crops that grow upon seven-eighths of the arable land of this country.*

III.—PRODUCTION OF CARBONIC ACID BY THE NATURAL DECAY OF VEGETABLE MATTER. LAW OF THIS DECAY.

Over large tracts of country in every part of the globe, the vegetable productions of the soil are never cropped or gathered, but either accumulate—as occasionally in our peat bogs; or decay and gradually disappear—as in the jungles of India, or in the tropical forests of Africa and Southern America.

The *final* results of this decay are the same as those which attend upon ordinary combustion, but the conditions under which it takes place being different, the *immediate* results are to a certain extent different also.

When a vegetable substance is burned in the air, the oxygen of the atmosphere is the only material agent in effecting the decomposition. The carbon of the burning body unites *directly* with this oxygen and forms carbonic acid.

In the natural process of decay, however, at the ordinary temperature of the atmosphere, vegetable matter is exposed to the action of both air and water; these both co-operate in inducing and carrying on the decomposition, and hence carbonic acid is not, as in the case of combustion, the chief or immediate result.

A detail of all the steps through which vegetable matter is known to pass before it is finally resolved into carbonic acid and water, would be difficult for you to understand, and is here unnecessary. A general view of the way in which by the united agency of air and water, the decay of organic substances is effected and promoted, may be made very intelligible, and will sufficiently illustrate the subject for our present purpose.

In combustion, as we have seen, the *whole* of the vegetable substance is resolved directly into carbonic acid and water, at the expense of the oxygen of the atmosphere. In natural decay a small and variable portion only is so changed, but to the extent to which this change does take place carbonic acid is directly formed and sent up into the air. Suppose such a change—a slow combustion in reality—to take place to a certain extent, and let us consider what becomes of the remainder of the vegetable matter.

1°. If we add

6 of CARBONIC ACID . . $= C^6 \quad O^{12}$ to

6 of LIGHT CARBURETTED HYDROGEN ($C H^2$) $= C^6 \quad H^{12}$ we have

The sum . . $= C^{12} H^{12} O^{12}$; or, one of grape-sugar;—that is, one of grape-sugar may be formed out of the elements of 6 of carbonic acid, and 6 of light carburetted hydrogen. Or, conversely, grape-sugar being already produced, it may be resolved or decomposed into these two compounds in the same proportions, without the aid of the oxygen of the atmosphere.

2°. So if to

1 of WOODY FIBRE = $C^{12} H^{8} O^{8}$ we add
4 of WATER . . = $H^{4} O^{4}$

Carbonic Acid. Light Carburetted Hydrogen.

We have, as before, $C^{12} H^{12} O^{12} = 6 CO^{2} + 6 CH^{2}$

Or by the aid of the elements of 4 atoms of water, woody fibre may be resolved into 6 of carbonic acid and as many of light carburetted hydrogen.

3°. Again, in the case of a vegetable acid, if to

1 of TARTARIC ACID = $C^{4} H^{2} O^{5}$ we add
1 of OXYGEN . . = O^{1}

Carbonic Acid. Light Carburetted Hydrogen.

We have $C^{4} H^{2} O^{6} = 3 C O^{2} + C H^{2}$

That is, by the aid of one of oxygen from the air, one of tartaric acid may be resolved into 3 of carbonic acid, and 1 of light carburetted hydrogen. It is easy to see how any other of the more common vegetable productions may—either at the expense of its own elements, as in grape-sugar—or by the aid of those of water, as in woody fibre—or of the oxygen of the atmosphere, as in tartaric acid—be resolved into carbonic acid and light carburetted hydrogen, in certain proportions.

Now such a resolution does really take place to a considerable extent in nature, during the decay of organic substances in moist situations. Hence the evolution of light carburetted hydrogen from dead vegetable matter in marshy places and stagnant pools—hence the production of the same gas in compost heaps, and especially in rich and heated farm-yard manure—and hence also its occurrence in such vast quantities in many of our coal mines.

You will now be able to appreciate one of the reasons why this light carburetted hydrogen has been supposed by some physiologists (p. 65,) to contribute as food to the ordinary nourishment of plants. It is produced in nature in many and varied situations, and it has been found by experiment to exercise a visible influence upon the growth of plants;—being so produced where young plants grow, is it never imbibed by them?—being possessed of this influence, is it entrusted with no control over the general vegetation of the globe?

However this may be, by far the greatest portion of both these gases escapes into the air;—the carbonic acid to fulfil those purposes which have already been considered,—the light carburetted hydrogen to undergo a further change, by which it also is resolved into carbonic acid and water. Thus, if to

1 of LIGHT CARBURETTED HYDROGEN $= C\,H^2$ we add

4 of OXYGEN . . . . $= O^4$

Carbonic Acid. Water.

We have . $C\,H^2\,O^4$ or $C\,O^2 + 2\,H\,O$

Or one of this gas with 4 of oxygen may be changed into 1 of carbonic acid and 2 of water.

Now, when this gas escapes into the air it becomes diffused through a large excess of oxygen, and is thus ready, at any instant, to be decomposed. Through the atmosphere streams of electricity are continually flowing, and every wandering spark that passes athwart a portion of this mixture decomposes so much of the light gas, and produces in its stead the equivalent proportions of carbonic acid and watery vapour. Thus it happens that of the vast quantity of this and other combustible gases which are continually escaping into the air, so few traces are discernible even by the aid of the most refined processes of art. By a wise provision of nature such substances as are void of use to either animals or plants, if not speedily removed from the air altogether, are there converted into such new forms of matter as are fitted to minister to the necessities of living beings.

Though therefore in the natural decay of vegetable matter in the presence of air and moisture, a certain portion of its carbon escapes into the air in the form of light carburetted hydrogen—this compound is but a step towards the final change into carbonic acid and water. In the soil the vegetable matter is continually undergoing decay, various substances are produced in greater or less quantity, some solid, some liquid, and some gaseous like the light gas of which we have been speaking,—but all of them, like this gas, are only hastening—some by one road, so to speak, and some by another—towards that final destination which sooner or later they are all fated to reach; when in the form of carbonic acid and water they shall be in a condition to minister again to the nourishment of all plants.

While in the soil some parts of this vegetable matter assumes forms which are capable of entering again into the roots of living plants, and, without further resolution in the air, of being converted by the living plant into portions of its own substance. The nature and composition of these forms of matter, so far as they are known, will be considered in a subsequent lecture.*

It is upon the *final* result of this natural decay to which all vegetable matter is subject, that the carbonic acid of the atmosphere depends for its largest supplies. The rapidity with which organized bodies perish, and become resolved into gaseous compounds, depends partly upon the climate and partly on the nature of the substances themselves,—but all hurry forward to the same end, and it is with difficulty that we are able for a time to arrest or even to retard their steps. It is by this perpetual and active obedience of all dead matter to one fixed law that the existing condition of things is maintained;—and thus it happens that either by the respiration of the animals which live upon it, by the process of combustion, or by that of spontaneous decay, the entire crop of vegetable produce is *apparently*, year by year—taking the average of a series of years—resolved into the forms of matter from which it was originally built up;—and the substances on which plants feed at length restored to the air in the precise proportion in which they have been taken from it.

VI.—NATURAL EVOLUTION OF CARBONIC ACID IN VOLCANIC COUNTRIES.

The above *apparent* conclusion would be absolutely true, were there no causes in operation by which the restoration to the air of a portion of the carbon of animal and vegetable substances is prevented—and no other sources, independent of existing organic matter, from which carbonic acid may be supplied to the air.

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* See in Part II. the Lecture "*On the constitution of soils.*"

If the whole of the carbon be not returned to the air, the carbonic acid of the atmosphere may be undergoing diminution; while—if a large supply be constantly poured into the air from sources independent of vegetable matter, the proportion of carbonic acid may be continually on the increase.

We have seen that the combustion of fossil coal adds to the air a large quantity of carbonic acid which has never before existed in the atmosphere of our time. In many volcanic districts also, carbonic acid is observed to issue in large quantity from cracks and fissures in the earth;—accompanied sometimes by water, forming mineral springs, from which the copious emission of gas is readily perceived; more frequently, perhaps, rising up alone, and thus escaping general observation.

It must obviously be exceedingly difficult to estimate the quantity of gas which rises into the air in such circumstances over an extensive tract of country, fractured and broken up by volcanic agency—where the outlets are numerous, and the rate at which the gas escapes very variable. That in many localities it must be very great, however, there can be no question. In the ancient volcanic district of the Eifel, comprising an area of many square miles around the Laacher See, on the left bank of the Rhine, the annual evolution of carbonic acid from springs and fissures has been estimated by Bischof at not less than 100,000 tons, containing 27,000 tons of carbon. In many other districts, especially where active volcanoes exist, the volume of gas given off may be quite as great, though no attempts have hitherto been made to estimate its real amount.

Yet though absolutely large, the quantity of carbonic acid disengaged in this way from the earth is really small when compared either with the entire quantity supposed to be present in the atmosphere, or with that which is required for the growth of the yearly vegetation of the globe. Suppose that from a thousand spots on the earth's surface a quantity of carbonic acid equal to the above estimate of

Bischof escapes constantly into the air, the weight of carbon (27 millions of tons) thus diffused through the atmosphere would be only equal to that which is yearly drawn from the air by 54 millions of acres of land under cultivation (p. 219), and only twice as much as that contained in the coal which is annually consumed in Great Britain alone.

Still if the *whole* of the carbon contained in the produce of the general vegetation of the globe be ultimately restored to the air,—either by the respiration of animals, by the natural and slow decay of vegetable matter, or by the more rapid process of combustion,—the constant addition of carbonic acid derived from volcanoes, and from the combustion of fossil coal, should gradually, though slowly, augment the proportion of this gas in the air we breathe;—unless it be perpetually undergoing a permanent diminution, to at least an equal extent, from the operation of other causes. In reference to this point there are three circumstances which are proper to be considered:—

1°. It has been observed that, as we recede from the land and approach the centre of great lakes, or sail into the open sea, the quantity of carbonic acid in the air gradually diminishes. It is therefore inferred that the sea is constantly, and to a sensible extent, absorbing carbonic acid from the atmosphere, without afterwards restoring it, so far as is yet known, by any compensating process.

2°. The waters which flow into the sea or great lakes constantly bear down with them portions of animal and vegetable matter. These fall along with the mud which the waters hold in suspension, and are permanently imbedded in the deposits of clay, silt, and sand, which are continually in the course of formation.

3°. In many parts of the world, especially in the latitudes North and South of 45°, vegetable matter accumulates in the form of peat, becomes buried beneath clay and sand, and thus is prevented from undergoing the ordinary process of natural decay.

It is impossible to say how much carbon is permanently withdrawn from the atmosphere by these several agencies. There is reason to believe that it is quite as great as the quantity added to the air by the combustion of coal, and by the evolution of carbonic acid in volcanic districts. Indeed, the supply from these two sources appears to return only a small portion of that carbonic acid which is abstracted from the air by the agencies just stated, and which have been in operation during every geological epoch.

Conclusions.—The general conclusions, therefore, which we seem justified in drawing in regard to the supply of carbonic acid to the atmosphere are as follow:—

1°. That a large portion of the carbonic acid absorbed by plants is immediately and directly restored to the air by the respiration of the animals which feed upon vegetable productions.

2°. That a still larger portion is more slowly returned by the gradual re-conversion of vegetable substances into carbonic acid and water during the process of natural decay.

3°. That *nearly all* the remainder is given back in the results of ordinary combustion.

4°. That a further portion, which has not previously existed in the atmosphere of our time, is conveyed to it by the burning of fossil fuel, and by the emission of carbonic acid from cracks and fissures in the surface of the earth; yet that the quantity thus added cannot be supposed to exceed that which is constantly and *permanently* separated from the atmosphere by other causes.

The balance of all the evidence we possess is probably in favour of the opinion that the carbonic acid in the atmosphere is slowly diminishing; we have, however, no satisfactory evidence either from theory or experiment that it has undergone any sensible diminution in our time.*

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* In another work (*Chemical Geology*) now preparing for publication, I have discussed this question in connection with purely Geological considerations and without reference *to our time;* but it would be out of place to introduce here any train of reasoning which is not calculated to throw light on the phenomena of the existing vegetation of the globe.

§ 4. *Of the supply of Ammonia to plants.*

In a previous lecture it has been shown that in our cultivated fields plants derive a portion of their nitrogen from the manure which is added to the soil. But the quantity of this element present in the manure, supposing it all taken up and appropriated by the plant, is seldom equal to that contained in the series of crops which this manure assists in raising.

Thus, in the experiments of Boussingault already described (p. 215), the manure added previous to the first, or four years' course, contained 157 parts of nitrogen, while the crops contained 251 parts,—or *nearly two-thirds more than could be derived from the artificial manure.*

Whence is this excess of nitrogen derived, and in what form does it enter into the plant? Liebig replies to these questions, that the whole of the nitrogen absorbed by plants enters in the state of ammonia, and that the excess above what is present in the manure is drawn either from the soil or from the air. This opinion, advanced by so high an authority, demands our attentive consideration.

Ammonia has been detected in many clays, and traces of it may be discovered in most soils, but it is not known to be a natural or essential constituent of any of the solid rocks of which the crust of the globe is composed. These clays and soils, therefore, may be supposed to have derived their ammonia from the atmosphere; and Liebig ascribes the fertilizing action of the air upon stiff clays when fallowed, of burned clay when applied as a top-dressing, and of gypsum on grass* lands, to the larger quantity of ammonia which the surface of the soil is by these means caused to absorb and retain.

There is no question that ammonia is present in the atmosphere in small and variable quantity (p. 45). Whence is this ammonia derived, and is its quantity sufficient to supply the demands of the entire vegetation of the globe?

When animal substances undergo decay, nearly all the nitrogen they contain is ultimately separated from the other

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[*] See note to page 70.

constituents in the form of ammonia. During the decay of plants also, a portion of their nitrogen escapes in the state of ammonia. Of the ammonia thus formed, much ascends into the air, chiefly in combination with carbonic acid as carbonate of ammonia (smelling salts), and much remains in the soil. Were the whole of the nitrogen contained in plants and animals to assume the form of ammonia when they decay, and to remain in the soil or in the air, it would always be within the reach either of the roots or leaves of the living races; and thus the same ammonia* might again and again return into the circulation of new vegetable tribes, and be always alone sufficient to supply all the demands of the existing vegetation of the globe.

But of the ammonia thus formed, a portion is daily washed from the soil by the rains and carried to the sea, and much more probably is washed from the air by the waters of the sea itself, or by the rains which fall directly into the wide oceans; and we know of no compensating process by which this ammonia can be restored to the air, and again made useful to vegetation.

Besides, of that which still remains in the air much must undergo decomposition by natural processes. In treating in a preceding section of the evolution of light carburetted hydrogen during the slow decay of vegetable matter (p. 228), I have shown how in consequence of its admixture with the oxygen of the atmosphere, this gas is finally decomposed, while carbonic acid and water are produced. Ammonia in like manner will burn in oxygen gas, and when mixed with atmospheric air may be decomposed by the eletric spark—water at the same time being formed and nitrogen set free. Thus, if with

$$\begin{array}{llll} \text{1 of AMMONIA} & = N\,H^3 & & \text{we mix} \\ \text{3 of OXYGEN} & = \quad\; O^3 & & \text{we have} \\ \cline{2-2} & & \text{3 of water} & \text{1 of nitrogen} \\ \text{the Sum} & N\,H^3\,O^3 & = 3\,H\,O & +\ N \end{array}$$

or, when diffused through the air, 1 of ammonia, with the aid of 3 of oxygen, will yield 3 of watery vapour, while the nitrogen may* mingle with the air in an elementary form. Can we doubt that ammonia is thus decomposed in the air? Not to speak of other forms assumed by the electricity of the atmosphere, can the thunder-storms of the tropical regions pass unheeded the ammoniacal vapours they must meet with in their course?

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* Or ammonia containing the same nitrogen—supposing the hydrogen to have been changed.

I conclude, then, that of the ammonia which is formed from the nitrogen actually existing in animal and vegetable substances during their decay, only a *comparatively* small portion ever returns again to minister to the wants of new races.†

But if plants obtain all their nitrogen from ammonia,‡ how is this waste repaired—whence are new supplies constantly derived?

We have seen that, in certain volcanic countries, carbonic acid is evolved in vast quantities from rents and fissures in the earth. In some of these districts—and this has been observed more especially in Italy and Sicily, and it is said also to some extent in China—ammonia is likewise given off, in combination generally with some acid, and most frequently with the muriatic acid in the form of sal-ammoniac (muriate of ammonia). "*This ammonia,*" Liebig is correct in saying, "*has not been produced by the animal organism;*" but he assumes a very doubtful position when he adds, "*it existed before the creation of human beings; it is a part, a primary constituent of the globe itself.*"§

Where, we might ask, has this ammonia existed during all past time—from what deep caverns of the earth does it now escape?

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* I say *may*, because it may at the same time combine with oxygen and form nitric acid.—See the following section, p. 239.

† I might add, that of the ammonia which does return, and is again absorbed, a portion is subsequently decomposed in the interior of living plants, as is shown by the evolution of nitrogen from the common leaves of some and the flower leaves of others.

‡ "Wild plants obtain *more nitrogen from the atmosphere, in the form of ammonia, than they require for their growth*, FOR the water which evaporates through their leaves and blossoms emits, after a time, a putrid smell—a peculiarity possessed only by such bodies as contain nitrogen." Liebig, *Organic Chemistry applied to Agriculture*, p. 85. Does the fact here stated, justify the conclusion which appears to be drawn from it?

§ *Ibid*, p. 112.

This opinion of Liebig, as well as the paramount influence he ascribes to ammonia over the vegetation of the globe, are based chiefly on the fact that we know of no means by which ammonia can be formed by the *direct* union of the hydrogen and nitrogen of which it consists.

But the production of ammonia, by the *indirect* union of these elements, is daily going on in nature, and can even be effected by different processes of art. Thus—

1°. When organic substances, which contain no nitrogen, are oxidized in the air, ammonia is not unfrequently formed (Berzelius). Hence it must be produced in unknown quantity during the annual decay of all vegetable substances.

2°. When inorganic substances are oxidized in the presence of air and water—as when moist iron filings are exposed to the air (Chevallier), or when certain oxidized substances are decomposed in the air by means of potassium (Faraday), or when metals, such as tin filings, are rapidly oxidized by means of nitric acid, ammonia is also produced in variable quantity. Hence the absorption of oxygen, even by the inorganic substances of the soil, may give rise to the formation of ammonia. But,

4°. The fact which most clearly illustrates the production of ammonia in nature, both on the surface of the earth in the soil, and far in the interior near the seat of volcanic fires, is this, that if a current of moist air be made to pass over red-hot charcoal, carbonic acid and ammonia are simultaneously formed.* This is in reality only a repetition in another form of what takes place, as above stated, when vegetable matter decays, or iron filings rust in moist air.

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* This experiment is easily performed by *drawing* a current of mixed atmospheric air and steam through a red-hot gun-barrel filled with well-burned charcoal, and causing the current, on leaving the barrel, to pass through water acidulated with muriatic acid. After a time, the water on evaporation, will be found to contain traces of sal-ammoniac. What thus takes place in a small experiment of this kind must more readily and more largely take place in the interior of the earth, where combustible substances at a high temperature happen to be exposed to a current of atmospheric air, mixed with watery vapour.

The carbon and the iron decompose the watery vapour in the air, and combine with its oxygen, while, at the instant* of its liberation, the hydrogen of the water combines with the nitrogen of the air, and forms ammonia.

The source of the ammonia evolved in volcanic districts, therefore, is no longer obscure. The existence of combustible matter in such districts, and at great depths beneath the surface, can in few cases be doubted, and the passage of a mixed atmosphere of common air and steam over such combustible matter, at a high temperature, appears to be alone necessary to the production of ammonia. It is unnecessary, then, to have recourse to doubtful speculations in order to account for the natural reproduction of ammonia, to a certain extent, in the place of that which is constantly undergoing decomposition by the agency of causes such as those above described.

But is the indefinite quantity of ammonia reproduced by these indirect methods sufficient to replace *all* that is lost ? Can it be supposed to impart to plants all the nitrogen they require ? These questions will be considered in the following section.

§ 5. *Of the supply of nitric acid to plants.*

In regard to the action of nitric acid upon vegetation it is known—

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* A beautiful illustration of the tendency which elementary substances have to unite with each other at the *instant* of their liberation in what chemists call their *nascent* state, is mentioned by Runge.—*Einleitung in die technische Chemie*, p. 373.

If 1 part of the hydrate of potash and 20 of iron filings be heated together, *hydrogen only is given off*.

If 1 of nitrate of potash and 20 of iron filings be heated together, *nitrogen only is given off*.

But if 40 of iron filings be mixed with 1 of hydrate and 1 of nitrate of potash, and then heated, *ammonia becomes perceptible*.

The nitrogen and hydrogen being given off together, and at the same instant, some portions of each find themselves in a condition to unite, and thus ammonia is produced. The same result must follow in many natural operations, when hydrogen, and nitrogen are set free from a previous state of combination, at the same time, and in the presence of one another.

1°. That when, in the form of nitrates of soda, potash, &c., it is spread upon the soil, it greatly promotes the growth and luxuriance of the crop and increases its produce; and

2°. That, when other circumstances are favourable to vegetation—as in certain districts in India—the presence of an appreciable quantity of these nitrates adds largely to the fertility of the soil.*

The same effects are unquestionably produced by the addition of ammonia or by its natural presence in the soil. The beneficial influence of both compounds, then, being recognized, the relative extent to which each operates upon the general vegetation of the globe will be mainly determined by the circumstances and the quantity in which they respectively exist or are reproduced.

In regard to the existence of nitric acid, it is not known to form a necessary constituent of any of the solid rocks of which the crust of the globe is composed, but is diffused almost universally through the soil which overspreads the surface. In the hotter regions of the earth, in India, in Africa, and in South America (p. 76), it in many places accumulates in sufficient quantity to form incrustations of considerable thickness over very large areas, and in many more it can be separated by washing the soil. Even in the climates of Northern Europe, it is rarely absent from the water of artificial wells, into which the rains, after filtering through the surface, are permitted to make their way.*

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* For the following and other interesting notices, regarding Indian agriculture, I am indebted to Mr. Fleming, of Barochan, in Renfrewshire, whose long residence in the districts to which he alludes, as well as the interest he takes in practical agriculture, renders his testimony very valuable:

"The districts of Chaprah, Tirhoot, and Shahabad, near Patna, where a large proportion of the saltpetre sent from Bengal is produced, are considered the most fertile in Bengal, producing 2 and sometimes 3 crops yearly. The natives of these districts, particularly a caste called Quirees (hereditary gardeners), who cultivate the best land, and produce the best crops, are in the habit of irrigating their fields with water from wells so strongly impregnated with saltpetre and other salts as to be quite brackish, and they consider onions, turnips, and peas, most benefitted by this irrigation. Grain crops also grow most luxuriantly on lands yielding saltpetre, where there is enough of rain within a week or two after the seed is sown, but if drought follows the sowing, and continues for 3 weeks or a month, the leaf becomes yellow and the crop fails.

"The Hindoos do not generally manure their lands, as the dung of the cattle is used for fuel, but the Quirees collect the ashes of cow dung and of burned wood, and use it as a manure in some cases, chiefly for the poppy plant.

"The Hindoos have for ages been well acquainted with the rotation of crops and the advantages of fallowing land, although a great proportion of the land is almost constantly in rice, Indian corn, or millet, during the rainy season, and in wheat or peas during the dry season."

On the whole, nitric acid and its compounds, appear to *exist*, ready formed in nature, in larger quantity than either ammonia or any of its compounds.

Of these nitrates, as they do of ammonia, the rivers must be continually bearing a portion to the sea, but there are in nature unceasing processes of reproduction, by which not only this waste of the nitrates is repaired, but that further waste, also, which is caused by their absorption into the roots and subsequent decomposition in the interior of plants. Let us shortly consider these processes of reproduction.

1°. When a succession of electric sparks is passed through common air, nitric acid ($N\ O^5$), is slowly but sensibly formed. The currents of electricity which in nature traverse the atmosphere must produce the same effect, and the passage of each flash of lightning through the air must be attended by the formation of some portion of this acid.

After a thunder-storm plants appear wonderfully refreshed; in thundery weather they grow most luxuriantly, and other things being equal, those seasons in which there is much thunder are observed to be the most fruitful. Some have ascribed these results to the *immediate* agency of electricity on the growth of plants,† Is it not equally possible that they may be connected with this necessary production of nitric acid?

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* It occurs in the wells of the neighborhood of Berlin (Mitscherlich), in the form of nitrates of potash, lime, and magnesia, in the wells around Stockholm, and may be expected in all wells that are dug (Berzelius).—*Traité de Chemie*, iv., p. 71.

† Sprengel, *Chemie I.*, p. 99.

In the rain which fell during 17 thunder-storms, Liebig found nitric acid always present and generally in combination with lime and ammonia. In the rain which fell on 60 other occasions, he could detect it only twice. In minute quantity nitric acid is difficult to detect. How much then must be formed in a thunder-storm, even in our climate, to make the presence of this acid *always* appreciable in the rain that falls—how vast a quantity in those warmer climates, where such storms are so frequent and so appalling!

2°. When a mixture of ammonia with oxygen gas is exploded by passing an electric spark through it, a quantity of nitric acid is formed, even when the oxygen is not sufficient to oxidize the whole of the ammonia* (Bischof). Hence, if in the air, as we have seen reason to believe, the ammonia given off from decaying animal matters, and from other sources, be decomposed by the atmospheric electricity,—there will necessarily be formed at the same instant a portion of nitric acid, at the expense of the nitrogen of the ammonia itself. This nitric acid will, as necessarily, combine with some of the ammonia which still remains in the air. Hence the existence and production of *nitrate of ammonia* in the atmosphere, and the consequent presence of this acid along with ammonia in rain water.

Thus the very cause which in the preceding section was shown to operate in constantly diminishing the amount of ammonia in the air, and the operation of which certainly renders improbable the existence of this compound in the atmosphere in the large quantity supposed by some†—the same cause is at the same moment constantly reproducing nitric acid. And, though much of what is thus produced must necessarily, as in the case of ammonia, be carried down to the sea by the rains, or be directly absorbed by the waters of the ocean themselves, yet it is obvious that in whatever proportion we may suppose the ammonia of the air to reach the leaves and roots of plants, in no less proportion must the nitric acid, with which it is associated, be enabled to enter into the circulating system of the various tribes of living vegetables, that flourish on every quarter of the globe.

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* It was shown above (p. 234), that 1 of ammonia NH^3 requires 3 of oxygen to decompose it, forming 3 of water, and setting the nitrogen free. But, in reality, as Bischof has shown, the nitrogen is not wholly set free, but a portion both of its hydrogen and nitrogen combine with oxygen (are oxidized) at the same instant, forming simultaneously both water (HO), and nitric acid ($N\,O^5$).

† See especially Liebig's *Organic Chemistry applied to Agriculture*, p. 74.

3°. Again we have seen that, during the decay of vegetable substances in moist air, ammonia is formed at the expense of the hydrogen of the water and of the nitrogen ot the air. In consequence of, or in connection with, such decay, nitric acid is also largely produced in nature.

The most familiar, as well as the most instructive examples of this formation of nitric acid is in the artificial nitre-beds of France and the North of Europe. These are formed by mixing earth of different kinds with stable manure or other animal and vegetable matters, and exposing the mixture to the air in long ridges or conical heaps, which are occasionly watered with liquid manure, and turned over, to expose fresh portions to the air. After a time, perhaps once a year, the whole is washed, when the water which comes off is found to contain a variable quantity of the nitrates of potash, soda, lime, and magnesia, which are employed for the manufacture of saltpetre. In these nitre-beds it has been observed that the production of nitric acid either does not take place at all, or only with extreme slowness, unless animal and vegetable matter be present in considerable proportion. And yet the quantity of nitric acid which is formed is much greater than could be produced by the oxidation of the whole of the nitrogen contained in the organic matters present in the mixture.* It is also observed that the nitre-beds are more productive when a portion from one outer face of the heap is lixiviated from time to time, and the washed earth added to the other side, than when the whole is lixiviated at once, and again formed into a heap and exposed to the air.

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* Dumas, *Traité de Chemie II.*, p. 725. He adds that 100 lbs. of nitre contain the nitrogen of 75 lbs. of ordinary animal matter, supposed in a dry state, or of 300 or 400 lbs. in its ordinary state of moisture,—a much greater relative proportion of animal matter than is ever added to the heap.

It appears, therefore, that organic matters are in our climate necessary to cause the formation of nitric acid to *commence*, but that after it has begun it will proceed in the same heap for an indefinite period, and at the expense apparently of the *nitrogen of the air only.*

Compost heaps are in general only artificial nitre-beds, often unskilfully prepared and badly managed, producing, however, a certain quantity of nitrates, to the presence of which their effect on vegetation may not unfrequently be ascribed. To this fact we shall hereafter recur.

The soils in the plains of India, and in other similar spots in the tropical regions, may be regarded as *natural* nitre-beds, in which, the decay of organic matter being vastly more rapid than in our temperate regions, the production of nitric acid is rapid in proportion.*

4°. But in many localities in which the presence of organic matter is not to be recognized in sensible quantity, the production of this acid is observed to proceed with a constant and steady pace. Thus, from the walls of certain caves in Ceylon a layer is yearly pared off, which yields an abundant crop of saltpetre (Dr. John Davy). The celebrated Mammoth cave in Kentucky, situated in a limestone ridge, yields an inexhaustible supply of nitrate of lime. During the war with Great Britain, fifty men were constantly employed in lixiviating the earth of this cave, and in about three years the washed earth is said to become as strongly impregnated as at first. Through the cave, a strong current of air is continually rushing—inwards in winter and outwards during the summer months. On the plaster of old walls, especially in damp situations, an efflorescence of this and other nitrates is frequently observed over every part of Europe. In China, according to Davis, the old plaster of the houses is so much esteemed as a manure, that parties will often purchase it at the expense of a coating of new plaster. Old clay walls, and especially the walls of clay-built huts, are said to be very fertilizing to the land, when applied as a top-dressing, and in some parts of England, where the land is poor, the people are said to pile up the soil in the form of walls, in order to improve its quality. These latter facts seem to indicate that both in China and England nitric acid is produced in similar circumstances, and that to its production the fertilizing action of the old plaster, and of the *weathered* clay, is alike to be attributed.

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* We are as yet too little acquainted with the natural history of the district of Arica in South America, in which, as already stated (p. 76), the nitrate of soda has been accumulated in such large quantity, to be able to say to what *special* cause the accumulation is due. But as, from the description of Mr. Darwin, the locality appears to have been the site of an ancient lake, it is not unlikely that the nitrate may have been derived from the successive washings of a soil similar to that of India, by rains or periodical floods, which for a long period emptied themselves into or fed the lake.

In the cultivated soil also, this acid is formed in ordinary circumstances. Braconnot found nitrate of potash in the botanic garden at Nancy, in a portion of soil in which poppies (*papaver somniferum*) had grown luxuriantly for ten years in succession—in larger quantity in the soil surrounding the interlaced roots of an *esclepias incarnata*, growing in an ordinary flower-pot, with a hole in the bottom—as well as in moss earth, in which a plant of *euphorbia breoni* had been grown in a pot.* There is little reason to doubt, indeed, that nitrates are to be found, in greater or less quantity, in all cultivated soils.

I shall not enter into a detailed inquiry how this nitric acid is formed. It is probable that as in the atmosphere ammonia may be decomposed and give rise to the formation of nitric acid, so in the soil this acid may result from a similar decomposition, proceeding more slowly, but according to the same natural laws. In warm climates, indeed, it appears certain that the ammonia which is evolved or formed during the decay of animal and vegetable substances, does speedily, and to a great extent, undergo oxidation,† and thus give rise

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* *An de Chim. et de Phys.*, lxxii., p. 33 to 35.

† For the perfect oxidation of 1 of ammonia, no less than 8 of oxygen are required. Thus

$$\underset{\text{Ammonia.}}{\overset{\text{1 of}}{NH^3}} + 8O = \underset{\text{Nitric Acid.}}{\overset{\text{1 of}}{NO^5}} + \underset{\text{Water.}}{\overset{\text{3 of}}{3HO}}$$

to the greater abundance of nitric acid with which the tropical soils abound.

Thus in the economy of nature, much ammonia is decomposed in the soil also, and hence another cause for the constant diminution of the quantity of this compound in addition to those already detailed in the preceding section.

But besides the portion of this nitric acid, which owes its existence to the decomposition of ammonia, much, by far the greatest proportion in all probability, derives its origin from the union of the elements of the atmosphere itself. This direct union is effected in the *air*, as has been already shown, by the agency of atmospheric electricity; but it also takes place in the *soil* during the oxidation of the other elements contained in the organic matters which are there undergoing decay. The combination of the elements of ammonia in such circumstances proceeds on the principle that bodies themselves undergoing oxidation, *dispose* other substances in contact with them (in this instance the nitrogen of the air) to unite with oxygen also. The presence of lime, potash, &c. in the soil, further induces to this oxidation by the tendency of these substances to combine with the acid which is formed by this union of the elements of which nitric acid consists.

It is impossible precisely to estimate the quantity of nitric acid produced in these various ways, through these various agents, and in these varied circumstances, or to balance it *accurately* against the amount of ammonia continually reproduced, as we have seen, in nature, wherever the necessary conditions present themselves. But, as I formerly concluded, that the amount of nitric acid actually existing in the superficial deposits of our globe is greater than that of ammonia, so I think that, in regard to the reproduction also of these two compounds, the balance is in favour of the former.

Since, then, nitric acid is fitted, by the solubility of its compounds, to enter into the circulation of plants in any quantity—since, when applied to them, it does undoubtedly promote, in a remarkable degree, the growth of plants—and since, in nature, it is continually reproduced in every country, and under such varied circumstances—I cannot withhold myself from the conclusion, that, over the general vegetation of the globe, it holds with ammonia at least an equal sway, and is appointed to exercise at least an equal influence over the growth of plants, both in their natural and in their cultivated state.

Still the influence of each is not unvaried by locality or by climate. The extent of dominion exercised by the nitrates probably diminishes as we recede from the equator, while that of ammonia increases,—it may be in an equal proportion. The reason of this probable variation will appear in the following section.

§ 6. *Theory of the action of nitric acid and ammonia.*

These two compounds act so far in common as to yield a supply of nitrogen to the plants into which they enter. They do so, however, under conditions which may be considerably different, and may be attended by unlike chemical changes.

I.—THEORY OF THE ACTION OF NITRIC ACID.

1°. The nitric acid of the nitrates entering into the circulation of the roots will ascend to the leaf, and will there be decomposed in the same way as the carbonic and other similar acids are, by the action of the sun's rays. It is only in the light of day that carbonic acid is decomposed in the green parts of plants—so must it be, generally, with the nitric acid which ascends to the leaf. Its oxygen will be given off, while its nitrogen may be retained in the circulating system of the plant. The extent to which this decomposition will take place at each passage of the sap through the leaf will depend, in some degree, on the nature of the base (whether potash, soda, or lime) with which the acid is in combination, but much more on the intensity of the light to which the green parts of the plant are exposed, and on the temperature of the air in which the plant happens to grow.

2°. It is still uncertain whether this acid is capable of being decomposed in the roots or stems of plants where it is excluded from the light, though it is very probable that it may be so, especially in cases where the juices naturally contain substances in which hydrogen is present in excess, or where such compounds make their way into the circulation of plants from the manure that may be applied to their roots.

Thus in the pines, in which turpentine ($C^{40} H^{32}$) naturally abounds, such a decomposition may the more readily occur, inasmuch as it would not necessarily imply the production and evolution of any gaseous substance. Thus

1 of Oil of Turpentine, $= C^{40}H^{32}$ with the oxygen of
1 of Nitric Acid (NO^5,) $=$ O^5 gives

1 of Resin, ... $= C^{40}H^{32}\ O^5$

By uniting with the oxygen of the nitric acid, therefore, oil of turpentine, in such trees, might be changed into resin during its passage through the stem, while the nitrogen, being set free, might at the moment of its liberation, unite with other elements to form those parts or productions of the tree, into which this element enters as a necessary constituent.

The above must be considered merely as an illustration of the *kind* of changes which may possibly take place in the interior of certain plants, and in the absence of light, when the nitrates happen to be present. Were I to affirm that such changes actually do occur in the presence of nitric acid, the theoretical chemist would have a right to expect that several collateral questions should be discussed, the consideration of which would here be out of place.

3°. The nitrates may also act in another way, which does not involve the necessity of the total decomposition of the acid they contain. We know that in nature many substances are capable of inducing chemical changes in other compound bodies, without themselves undergoing decomposition. Some beautiful illustrations of this have already been given in a previous lecture, when treating of the action of sulphuric acid upon starch and woody fibre.* But the fact which most immediately bears on the influence of the nitric acid in the living plant, is that mentioned in p. 186,—that by solution in this acid in the cold, starch is converted into a substance having the composition of woody fibre. In the interior of the plant changes of this kind may be produced by simple contact only, with the nitric acid, so that, without being decomposed, it may be materially serviceable in promoting those molecular changes which are necessary to the healthy and rapid growth of the plant.

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* Lecture VI., pp. 165, 167.

II.—THEORY OF THE ACTION OF AMMONIA.

1°. Ammonia is capable of contributing to the growth of the plant, by means of the hydrogen, as well as of the nitrogen it contains. We have seen* that, according to the results of the best experiments, the whole of the oxygen of the carbonic acid absorbed, is not given off by the leaves of all plants even in the sunshine,—while in the dark this gas is largely and directly imbibed from the air. If in the sap of a plant there be present at the same time a quantity of ammonia, the hydrogen of this ammonia may unite directly with the oxygen of the carbonic acid, forming water and a proportionate quantity of one or other of the several compounds (p. 163), which may be represented by carbon and water. Thus

3 of CARBONIC ACID, = $C^3 \quad O^6$ and the hydrogen of
2 of AMMONIA (NH^3) = H^6

¼ of Grape Sugar. 3 of Water.

give . . . . . $C^3H^6O^6 = C^3H^3O^3 + {}^3HO$

so that where ammonia is present, and circumstances are favourable, sugar or starch may be formed in variable quantity, without the necessary evolution of oxygen gas. This change will take place in the interior of the leaf. And, if the direct decomposition of carbonic acid, and the evolution of its oxygen by the agency of the sun, take place at the same time—with a rapidity proportioned to the intensity of the light,—this simultaneous production of sugar, &c., from the presence of ammonia, must aid the increase and growth of the plant; and may be one main cause of the fertilizing action of this compound, which has been so long and so generally recognized.

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* Notes to pages 201 and 205.

When the hydrogen of the ammonia is thus worked up, the quantity of oxygen which escapes from the leaf must be less in proportion; and hence another cause (p. 205) for those discrepancies which have been observed in regard to the bulk of oxygen given off, compared with that of the carbonic acid taken in, by the leaves of different plants.

But at the same time the nitrogen is set free. This nitrogen will either be again compounded in the plant with other elements, or, if not required for its healthy growth—that is, if more largely present than is required by the plant—it will be directly emitted by the leaves, or sent downwards and permitted to escape by the root. Hence the reason why pure nitrogen is evolved from the leaves of some plants (p. 137), and why ammonia exercises a beneficial action upon vegetation, in cases where all the nitrogen it contains is neither retained nor required by the plant.

Does this decomposition necessarily require the agency of light? May it not take place in the absence of the sun?

I will mention one or two facts which seem to throw light upon this point.

1°. Plants grow in the dark. Though feeble and blanched they increase largely in bulk; they must, therefore, have the power of assimilating their food to a certain extent, *independent of the sun's rays.*

2°. Several species of Poa, Plantago, Trifolium arvense, Cheiranthus, &c., become green in the perpetual darkness of mines (Humboldt).

3°. When a little hydrogen is mixed with the air, plants become greenish, even in the dark (Sennebier); and when exposed to the sun, the green becomes unusually intense in such a mixture (Ingenhouss).

The immediate and visible effect of an application of ammonia, or of soot, or of any top dressing containing ammonia, is to render the green colour much more intense, and in the darkest weather. It is therefore probable, I think, that the hydrogen of the ammonia contributes to this immediate effect, and that the ammonia itself may be decomposed and its elements appropriated to the nourishment of the living vegetable, either by the unaided vital powers of the plant, or in the presence of a feeble light only. Like water, ammonia is *peculiarly* liable to decomposition, not always of that perfect kind which, *for the sake of simplicity,* I have endeavoured to explain in the present lecture, yet such as to render the elements of which it consists available to the general nourishment of the plant.

§ 7. *Comparative influence of nitric acid and of ammonia in different climates.*

It follows, from what is above stated, that the beneficial influence of ammonia upon vegetation will be readily perceived in all climates in which plants are found to flourish. Its effects will be greater and more rapid where the heat and light are more intense—only because by these agents the functions of all life are stimulated.

Not so with the nitric acid in the nitrates. In the presence of organic compounds, that is, in the sap of the plant, it is less easily decomposed than ammonia. It requires the interference of more powerful agents—of a higher temperature, or of more brilliant light,—and thus its efficacy upon vegetation will be more dependent upon season and climate.

Now, we have seen that in tropical countries the nitrates are produced in the greatest abundance, and there the high temperature and the brilliant sun should render them most useful to vegetation. Such is well known to be the case, and it may be regarded as one of those bountiful adaptations with which all nature is full—that in these warmer regions, the ammonia produced in the soil is first converted into nitric acid, that it may *remain fixed,* and that this acid again is decomposed by the same agents (light and heat), when it enters the living plant, and is required to minister to its growth. On the other hand, it may no less be regarded as a wise provision, that in colder and more uncertain climates, where warm and brilliant summers are less to be depended upon, that compound of nitrogen (ammonia) should more abound, which is most easily decomposed in the living plant, which is fitted in comparative darkness to yield up its nitrogen, and by the hydrogen it contains, to compensate in some slight degree for the partial absence of the sun's rays.

From these views, therefore, we should draw this further practical conclusion—that in our climate, ammonia is sure to promote vegetation, and in every season, while the nitrates will produce their *maximum* effect, other things being equal, in such only as have abundant warmth and sunshine. Is this conclusion consistent with observation? Will it serve to explain any of the apparent failures which have occasionally been experienced in the employment of the nitrates?

§ 8. *Stimulating influence of these compounds.*

There remains one other point in regard to the effect of these two compounds upon vegetation, to which I would request your attention. We have seen that the quantity of nitrogen contained in a crop raised by the aid of farm-yard manure, is very much greater than that which exists in the manure itself, and the views just exposed serve to indicate the sources from which the excess is derived. But suppose that upon two patches of ground, of equal quality, the one of which is manured and the other not, equal quantities of the same seed be sown, it is consistent with experience—that the crop reaped from the manured portion will not only contain more nitrogen than that reaped from the unmanured portion, but so much more as shall considerably exceed that contained in the manure also. Thus suppose the crop raised from the unmanured land to contain 100 lbs. of nitrogen, and that the manure laid on the other portion contained 100 lbs. also, the crop which is reaped from this latter portion, in favourable seasons, will exceed, and probably very far exceed, 200 lbs. Hence the effect of the ammonia, &c., in the farm-yard manure, is not merely to yield its own nitrogen to the plant, but to enable it in some way hitherto unexplained, to draw from other sources a larger portion of the same element than it would otherwise do.

So also with the nitrates. If two equal portions of the same grass or corn-field, in early spring, be measured off, and one of them be top-dressed with nitrate of soda or with saltpetre, the weight of nitrogen contained in the crop of hay or corn reaped from the latter, will generally be found to exceed that contained in the crop from the former, by a quantity much greater than that which was present in the nitrate with which the land was dressed.* In addition, therefore, to the nitrogen directly conveyed to the plant by these nitrates, they also exercise some other influence, by which they enable the living vegetable to draw from natu-

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* The following calculations illustrate the statement in the text:—Mr. Gray, of Dilston,† applied nitrate of soda to grass land in the proportion of 112 lbs. to the acre.

The produce without nitrate amounted to	2 tons	81 stones
" " with 112 lbs. of nitrate to	3 tons	146 stones
Increase,	1 ton	65 stones
	or 3150 lbs.	

And 3150+112 = 28⅛ lbs. the increase of hay from each pound of nitrate of soda.‡ But allowing this hay to contain only 1 per cent. of nitrogen, 28 lbs. will contain 4½ ounces of nitrogen, which is nearly double the quantity actually present in the nitrate employed.

Again, in the case of a crop of grain—Mr. Hyett applied nitrate of soda to a field of wheat, and compared the produce with that from an equal portion to which no top-dressing was applied.

	CORN.			STRAW.		
	Bush.	pks.	pts.	Cwt.	qrs.	lbs.
Nitrated . .	43	2	11	31	2	3
Without nitrate	33	2	6	23	1	21
Excess,	10	0	5	8	0	10

Calculating the bushel of corn at 60 lbs., the excess of corn amounted to 600 lbs., containing 24½ per cent. or 147 lbs. of gluten and albumen. The nitrogen in these substances, when properly dried, is from 15 to 17 per cent. If we suppose the gluten not to have been quite dry, and allow only 14 per cent. of nitrogen, 147 lbs. would contain 20½ lbs. of this element.

But the nitrated corn contained 5 per cent. more gluten and albumen than

[† See Journal of Royal English Agricultural Society.]

[‡ Dry nitrate of soda contains about 16½ per cent. of nitrogen, being 19 lbs. to the cwt., or two and three-fifth ounces to the pound; but as it is usually applied, it contains from 5 to 10 per cent. of water. The nitrogen, therefore, may be estimated at 2½ ounces in the pound.]

ral sources a much larger supply than they would otherwise be capable of doing. What is this influence, and how is it explained?

This I suppose to be that kind of influence to which writers on agriculture are in the habit of alluding, when they speak of certain substances *stimulating* plants, or acting as *stimulants* to their growth, though the term itself conveys to the mind no distinct idea of the mode of operation intended to be indicated—of the way in which the effect is produced.

In the present case, this special action of ammonia and the nitrates, and perhaps also of immediate applications of manure in general, appears to arise from their affording to the plant, in its early youth, a copious supply of nitrogenous food, by which it is enabled at once to shoot out in a more healthy and vigorous manner. It thrusts forth the roots in greater numbers, and to greater distances, and is thus enabled to extract nourishment from a greater extent and depth of soil than is ever reached by the sickly plant—it expands larger and more numerous leaves, and thus can extract from the air more of every thing it contains which

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the un-nitrated, which in 33 bushels (2000 lbs.) gives 100 lbs. of gluten in excess, containing 14 lbs. of nitrogen.

And 8 cwt. of straw (900 lbs.) contained one-third of a per cent. of nitrogen*, or in all 3 lbs.

Therefore the quantity of nitrogen present in the nitrated crop above that in the un-nitrated was as follows:

	Nitrogen.
1°. In 600 lbs. of wheat at 24½ per cent. of gluten .	20½ lbs.
2°. In 2000 lbs. of wheat at 5 per cent. of gluten contained in excess	14 lbs.
3°. In 900 lbs. of straw at one-third per cent. . .	3 lbs.
Total nitrogen .	= 37½ lbs.

But the nitrogen in 1 cwt. of dry nitrate of soda, as already stated, is only 19 lbs. or little more than half the quantity, which in consequence of the presence and action of the nitrate the wheat was enabled to obtain and appropriate above the quantity appropriated by the wheat in the un-nitrated part of the field.

It requires no further proof, therefore, to show that *the nitrate of soda and the nitrates must act in some other way in reference to vegetation, than by simply supplying a portion of nitrogen.*

[* Boussingault.]

is fitted to supply the wants of the living vegetable ; as the stout and healthy savage can hunt and fish to support many lives, while the feeble or sickly can scarcely secure sustenance for himself alone. Feed a wild animal well the first few months of its life, and you may set it loose to prey for itself; starve it in its infancy, and its growth and strength will be stunted, and it may lead a wretched and hungry life.

Even in soils, then, and situations, which are capable of yielding to the plant every thing it may require for its ordinary growth, it is an important object of the art of husbandry to discover what substances are especially *necessary* or grateful to particular crops, and to apply *these directly, and in abundance*, to the new-born plant—in order that it may acquire sufficient strength to be able to avail itself in the greatest degree of the stores of food which lie within its reach.

Concluding observations regarding the organic constituents of plants.

We have now considered the most important of those questions connected with the organic elements of plants, which are directly interesting to the practical agriculturist. We have seen—

1°. That all vegetable productions consist of two parts—one the organic part, which is capable of being burned away in the air—the other, the inorganic part, which remains behind in the form of ash.

2°. That this organic part consists of carbon, hydrogen, oxygen, and nitrogen only.

3°. That plants derive the greater part of their carbon from carbonic acid, of their hydrogen and oxygen from water, and of their nitrogen from ammonia and nitric acid.

4°. That by far the largest portion of those substances which form the principal mass of plants, such as starch and woody fibre, consists of carbon united to oxygen and hydrogen in the proportions in which they exist in water,—or, in other words, may be represented by carbon and water in various proportions.

5°. That the food on which they live enters by the roots and leaves of plants,—that the leaves under the influence of the sun, decompose the carbonic acid, give off its oxygen, and retain its carbon,—and that this carbon, uniting with the elements of water in the sap, forms those several compounds of which plants chiefly consist.

6°. That the supply of carbonic acid in the atmosphere is kept up partly by the respiration of animals, partly by the natural decay of dead vegetable matter, and partly by combustion. That ammonia is supplied to plants chiefly by the natural decay of animal and vegetable substances—and nitric acid partly by the natural oxidation of dead organic matter, and partly by the direct union of oxygen and nitrogen, through the agency of the atmospheric electricity.

7°. That while both of these compounds yield nitrogen to plants, they each exhibit a special action on vegetable life, in virtue of the hydrogen and oxygen they respectively contain—and exercise also a so-called *stimulating* power, by which plants are induced or enabled to appropriate to themselves, from other natural sources, a larger portion of all their constituent elements than they could otherwise obtain or assimilate.

In illustrating these several points, it has been necessary to enter occasionally into details which, to those who have heard or may read only the later lectures, may not be altogether intelligible. I am not aware, however, of having introduced any thing of which the full sense will not appear on a reference to the statements by which it is preceded.

We are now to consider the *inorganic* constituents of plants,—their nature,—the source (the soil) from which they are derived,—their uses in the vegetable and animal economy,—how the supply of these substances is kept up in nature,—and how, in practical husbandry, the want of them may be at once *efficaciously and economically supplied by art.* This division of our subject, though requiring a previous knowledge of the principles discussed in the foregoing lectures, will be more essentially of a practical nature, and will lead us to consider and illustrate the great leading principle by which the practical agriculturist ought to be guided in the cultivation and improvement of his land.

We shall here also find much light thrown upon our path by the results of geological inquiry; and it is in the considerations I am now about to bring before you, that I shall have to direct your attention most especially to the principal applications of Geology to Agriculture.

LECTURES

ON THE

APPLICATION OF CHEMISTRY AND GEOLOGY

TO

AGRICULTURE.

Part II.

ON THE INORGANIC ELEMENTS OF PLANTS.

LECTURE IX.

Inorganic constituents of vegetable substances. Relative proportions of organic and inorganic matter in plants. Unlike proportions in unlike species. Kind of inorganic matter which exists in different species. Nature and properties of the several inorganic elementary bodies found in plants.

THE consideration of the *inorganic* constituents of plants is no less important to the art of culture than the study of their organic elements, which has engaged our sole attention in the preceding part of these lectures.

It has already been shewn that when vegetable substances are heated to redness in the air, the whole of the so-called organic elements—carbon, hydrogen, oxygen, and nitrogen—are burned away and disappear; while there remains behind a *fixed* portion, commonly called the ash, which does not burn, and which in most cases undergoes no diminution when exposed to a red heat. This ash constitutes the *inorganic* portion of plants.

The organic or combustible part of plants constitutes, in general, from 88 to 99 per cent. of their whole weight, even after they are dried. Hence the quantity of ash left by vegetable substances in the green state, is often exceedingly small. It therefore long appeared to many, that the inorganic matter could be of no essential or vital consequence to the plant—that being, without doubt, derived from the soil, it was only accidentally present,—and that it might or might not be contained in the juices and solid parts of the living vegetable, without materially affecting either its growth or its luxuriance.

Were this the case, however, the quantity and quality of the ash left by the same plant should vary with the soil in which it grew. If one soil contained much lime, another much magnesia, and a third much potash, whatever plant was grown upon these several soils should also contain in greatest abundance the lime, the magnesia, or the potash, which abounded in each locality—and the nature, at least, of the ash, if not its proportion, should be nearly the same in every kind of plant which is grown upon the same soil.

Careful and repeated experiments, however, have shewn—

1°. That on whatever soil a plant is grown, if it shoots up in a healthy manner and fairly ripens its seed, the quantity and quality of the ash is nearly the same; and

2°. That though grown on the same soil, the quantity and quality of the ash left by no two species of plants is the same—and that the ash differs the more widely in these respects, the more remote the natural affinities of the several plants from which it may have been derived.

Hence there is no longer any doubt that the inorganic constituents contained in the ash are really essential parts of the substance of plants,—that they cannot live a healthy life or perfect all their parts without them,—and that it is as much the duty of the husbandman to supply these inorganic substances when they are wanting in the soil, as it has always been considered his peculiar care to place within the reach of the growing plant those decaying vegetable matters, which are most likely to supply it with organic food.

For the full establishment of this fact, we are indebted to Sprengel. Others, as de Saussure, have published many important and very useful analyses of the inorganic matters left by plants, but for the illustration of the important practical bearing of this knowledge of their inorganic constituents on the ordinary processes of agriculture, we are, I believe, in a great measure indebted to the writings and numerous analytical researches of Sprengel.

It is difficult to conceive the extent to which the admission of the essential nature and constant quality of the inorganic matter contained in plants, must necessarily modify our notions and regulate our practice in every branch of agriculture. It establishes a clear relation between the kind and quality of the crop, and the nature and chemical composition of the soil in which it grows—it demonstrates what soils ought to contain, and, therefore, how they are to be improved—it explains the effect of some manures in permanently fertilizing, and of some crops in permanently impoverishing the soil—it illustrates the action of mineral substances upon the plant, and shews how it may be, and really is, in a certain measure, *fed* by the dead earth:—over nearly all the operations of agriculture, indeed, it throws a new and unexpected light. Of this, I am confident, you will be fully satisfied when I shall have discussed the various topics I am to bring before you in the present part of my lectures.

§ 1. *Of the relative proportions of inorganic matter in different vegetable substances.*

As above stated, the inorganic matter contained in different vegetable productions varies from 1 to 12 per cent. of their whole weight. The following table exhibits the weight of ash left by 100 lbs. of the more commonly cultivated plants—according to the analyses of Sprengel* :—

Grain of	Per ct.
Wheat . .	1·18 lbs.
Rye . .	1·04
Barley . .	2·35
Do. dried at 212	2·52 J.
Oats . .	2·58
Field Beans .	2·14
—— Peas .	2·46

Dry straw of	Per ct.
Wheat . .	3·51 lbs.
Oats . .	5·74
Barley . .	5·24
Rye . .	2·79
Beans . .	3·12
Peas . .	4·97

	Undried.	Dried in air.†
Potato . .	0·83 lbs.	2·65 lbs.
Turnip . .	0·63	7·05
Do. white .	0·8 J.	
Carrot . .	0·66	5·09
Parsnip . .	0·82	4·34
Leaf of Potato .		4·79
—— Turnip	1·8	2·91
—— do. white	2·18 J.	
—— Carrot	1·98	10·42
—— Parsnip	3·00	15·76
—— Cabbage	0·53	7·55

	Green.	In hay.
Lucerne . .	2·58 lbs.	9·55 lbs.
Red Clover .	1·57	7·48
White Clover .	1·74	9·13
Rye Grass .	1·69	5·3

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* *Chemie*, vol. ii., passim.

† Of the substances in this column the potato lost by drying in the air 69 per ct. of water, the turnip 91, the carrot 87, the turnip leaf 86, the carrot leaf, the parsnip, and the parsnip leaf, each 81, and the cabbage leaf 93 per cent.

In the parts of trees dried in the air there are found of inorganic matter—

In the	Wood.	Leaves.	In the	Wood.	Leaves.
Elm . .	1·88	11.8	Oak	0.21	4·5
Willow .	0·45	8·23	Birch	0.34	5·0
Poplar .	1·97	9·22	Pitch pine . . .	0.25	3·15
Beech . .	0·36	6·69	Common furze .	0.82	3·1

In looking at the preceding tables, you cannot fail to be struck with one or two points, which they place in a very clear light.

1°. That the quantity of inorganic matter contained in the same weight of the different crops we raise, or of the different kinds of vegetable food we eat, or with which our cattle are fed, is very unlike. Thus 100 lbs. of barley, or oats, or peas, contain twice as much inorganic (earthy and saline matter that is) as an equal weight of wheat or rye—and the same is the case with lucerne and white clover hays, compared with the hay of rye grass.

2°. The quantity contained in different parts of the same plant is equally unlike. Thus 100 lbs. of the grain of wheat leave only 1½ lbs. of ash, while 100 lbs. of wheat straw leave 3½ lbs. So the dry bulb of the turnip gives only 7 per cent., while the dry leaf leaves 13 per cent. of ash when it is burned. The dry leaves of the parsnip also contain nearly 16 per cent., though in its root, when sliced and dried in the air, there are only 4½ per cent. of inorganic matter.

In trees the same fact is observed. The wood of the elm contains less than 2 per cent., while its leaves contain nearly 12 per cent.;—the wood of the oak leaves only ⅕th of a per cent., while from its leaves 4½ per cent. or 22 times as much are obtained. The leaves of the willow and of the beech also contain about twenty times as much as the wood of these trees does, when it has been dried under the same conditions.

These differences cannot be the result of accident. They are constant on every soil, and in every climate; they must, therefore, have their origin in some natural law. Plants of different species must draw from the soil that proportion of inorganic matter, which is adapted to the constitution, and is fitted to supply the wants of each ;—while of that which has been admitted by the roots into the general circulation of the plant, so much must proceed to and be appropriated by each part, as is suited to the functions it is destined to discharge. And as from the same soil different plants select different quantities of saline and earthy matter, so from the same common sap do the bark, the leaf, the wood and the seed, select and retain that proportion which the healthy growth and development of each requires. It is with the inorganic, as with the organic food of plants. Some draw more from the soil, some less, and of that which circulates in the sap, only a small portion is expended in the production of the flower, though much is employed in forming the stem and the leaves. On the subject of the present section, I shall add two other observations.

1°. from the constant presence of this inorganic matter in plants, and from its being always found in nearly the same proportion in the same species of plants,—a doubt can hardly remain that it is an essential part of their substance, and that they cannot live and thrive without it. But that it really is so, is placed beyond a doubt, by the further experimental fact, that if a healthy young plant be placed in circumstances where it cannot obtain this inorganic matter, it droops, pines, and dies.

2°. But if it be really essential to their growth, this inorganic matter must be considered as part of the *food* of plants ; and we may as correctly speak of feeding or supplying food to plants, when we add earthy and mineral substances to the soil, as when we mix with it a supply of rich compost, or of well fermented farm-yard manure.

I introduce this observation for the purpose of correcting an erroneous impression entertained by many practical men in regard to the way in which mineral substances act when applied to the soil. By the term *manure* they generally designate such substances as they believe to be capable of *feeding* the plant, and hence reject mineral substances, such as gypsum, nitrate of soda, and generally lime, from the list of manures properly so called. And as the influence of these substances on vegetation is undisputed, they are not unfrequently considered as *stimulants* only.

Yet if, as I believe, the use of a wrong *term* is often connected with the prevalence of a wrong *opinion*, and may lead to grave errors in practice;—I may be permitted to press upon your consideration the fact above stated—I may almost say demonstrated—that plants *do feed* upon dead unorganized mineral matter, and that you are, therefore, really manuring your soil, and permanently improving it, when you add to it such substances *of a proper kind*.

§ 2. *Of the kind of inorganic matter found in plants.*

I have said above, *of a proper kind*—for it is not a matter of indifference to a plant, what kind of earthy or saline matter it takes in by its roots. Each species of plant, we have seen, withdraws from the soil a quantity of inorganic matter, which is peculiar to itself, and which, as a whole, is nearly constant.

So also each species, in selecting for itself a nearly constant weight of inorganic matter, while it chooses generally the same kind of saline and earthy ingredients as other plants do, to make up this weight, yet picks them out *in proportions peculiar to itself*. Thus for example, lime is present in the ash of nearly all plants, but while 100 lbs. of the ash of wheat contain 8 pounds of lime, the same weight of the ash of barley contains only 4½ lbs. So also potash is contained in the ash of most plants grown for food, but in the ash of the turnip, there are 37½ per cent, of potash, while in that of wheat there are only 19 per cent. Again, in different parts of the same plant, a like difference prevails. The ash of the turnip bulb contains 16½ per cent. of soda, that of the leaf, little more than 12 per cent. On the other hand, the lime in that from the bulb constitutes less than 12 per cent. of its weight, while in that of the leaf it amounts to upwards of 34 per cent.

These relative proportions among the different kinds of inorganic matter contained in the ash of plants—like the whole weight itself of the ash—is nearly constant in the same species, and in the same part of a plant, when it is grown in a propitious soil. It is not, therefore, as I have already said, a matter of indifference to the living vegetable, whether it meets with this or with that kind of inorgainc matter in the land on which it grows—whether its roots are supplied with lime, or with potash, or with soda. *The soil must contain all these substances, and in such quantity as easily to yield to the crop so much of each, as the kind of plant specially requires.* And if one of these necessary inorganic forms of matter be rare or wholly absent, the crop will as certainly prove sickly or entirely fail, as if the organic food supplied by the vegetable matter of the soil were wholly withdrawn. It is, therefore, as much the end of an enlightened agricultural practice to provide for the various requirements of each crop in regard to inorganic food, as it is to endeavour to enrich the land with purely vegetable substances.

Since, also, as above shewn, not only the relative quantity of inorganic matter, but its kind or quality, likewise, is different in different plants,—it may be, that a soil on which one crop cannot attain to maturity may yet surely and completely ripen another—a fact which is proved by every-day experience. The soil, which is unable to supply with sufficient speed all the lime or the potash required for one crop, may yet easily meet the demands of another, and afford an ample return to the husbandman when the time of harvest comes.*

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* On the same principle also, some of the interesting facts connected with the grafting of trees are susceptible of a satisfactory explanation.

The root of a tree selects from the soil the *kind* and *quantity* of inorganic matter which are required for the healthy maturity of its own parts. Any other tree may be grafted on it, which in its natural state requires the same kind of inorganic matters in nearly the same proportion. This is the case generally with varieties of the same species—more rarely with trees or plants of different species—and least frequently with such as belong to different genera. The lemon may be grafted on the orange, because the sap of the latter contains all the earthy and saline substances which the former requires, and can supply them in sufficient quantity to the engrafted twig. But the fig or the grape would not flourish or ripen fruit on the same stock—because these fruits require other substances than the root of the orange cares to extract from the soil, or in greater quantity than the sap of the orange can supply them.

It is not for want of organic food, for of this the sap of nearly all plants is full—and we have seen in our previous lectures, how the sugar of the fig, the tartaric acid of the grape, and the citric acid of the lemon, may all be produced by natural processes from the same common organic food. When we plant a tree or sow a crop on a soil no way affect the progress of vegetable growth, or require to occupy the attention of the practical agriculturist.

2°. They all, however, exist in nature more or less abundantly in a state of combination* with other substances, and chiefly with oxygen—but in no state of combination are they known to be generally diffused through the atmosphere of the globe, so as to be capable of entering plants by their leaves or other superior parts. They must all, therefore, enter by the roots of plants,—must consequently exist in the land,—and must all be necessary constituents of that soil in which the plants that contain them grow.

It will not be necessary, therefore, to consider so much the relative proportions in which these elementary bodies themselves exist in plants, as that of the several chemical compounds which they form with oxygen, or with one another—in which states of combination they exist in the soil, and are found in the circulation and substance of the plant. As a preliminary to this enquiry, however, it will be proper to lay before you, a brief outline of the nature and properties of these compound bodies themselves—and of the direct influence they have been found to exercise upon vegetable life.

§ 4. *Of those compounds of the inorganic elements which enter directly into the circulation, or exist in the substance and ash of plants.*

I.—CHLORINE AND MURIATIC ACID.

Chlorine. If a mixture of common salt and black oxide of manganese† be put into a flask or bottle of colourless glass, and sulphuric acid (oil of vitriol) be poured upon it, a gas of a greenish-yellow colour will be given off, and will gradually fill the bottle. This gas is distinguished by the name of *chlorine.*

It is readily distinguished from all other substances by its greenish-yellow colour, and its pungent disagreeable smell. It extinguishes a lighted taper, but phosphorus, gold leaf, metallic potassium and sodium, and many other metals, take fire in it and burn of their own accord. It is nearly 4½ times heavier than common air, and therefore may be readily poured from one vessel to another. Water absorbs twice its own bulk of the gas, acquiring its colour, smell, and disagreeable astringent taste.

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* For an explanation of the meaning and of the laws of chemical combination, see Lecture II., p. 37.

† Sold by this name in the shops.

Animals cannot breathe it without suffocation—and, when unmixed with air, it speedily kills all living vegetables. The solution of chlorine in water was found by Davy to promote the germination of seeds.

It does not exist, and is rarely evolved,* in nature in a free or uncombined state, and therefore is not known to exercise any *direct* action upon the general vegetation of the globe. It exists largely, however, in common salt (chloride of sodium), every 100 lbs. of this substance containing upwards of 60 lbs. of chlorine. Indirectly, therefore, it may be supposed to influence, in some degree, the growth of plants, where common salt exists naturally in the soil, or is artificially applied in any form to the land.

Muriatic acid, the spirit of salt of the shops, consists of chlorine in combination with hydrogen. It is a gas at the ordinary temperature of the atmosphere, but water absorbs between 400 and 500 times its bulk of it, and the acid of the shops is such a solution in water, of greater or less strength.

Muriatic acid has an exceedingly sour taste, corrodes the skin, and in its undiluted state is poisonous both to animals and plants. It dissolves common pearl ash, soda, magnesia, and limestone, with effervescence; and readily dissolves also, and combines with, many earthy substances which are contained in the soil.

When applied to living vegetables in the state of an exceedingly dilute solution in water, it has been supposed upon some soils, and in some circumstances, to be favourable to vegetation. Long experience, however, on the banks of the Tyne, and elsewhere, in the neighbourhood of the so-called alkali† works, has proved that in the state of vapour its repeated application, even when diluted with much air, is in many cases fatal to vegetable life.

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* See Lecture V., p. 136.

† In these works carbonate of soda (the common soda of the shops) and sulphate of soda (glauber salt) are manufactured from common

Poured in a liquid state upon *fallow* land, or land preparing for a crop, it may assist the growth of the future grain, by previously forming, with the ingredients of the soil, some of those compounds which have been occasionally applied as manures, and which we shall consider hereafter.

Chlorine is represented by Cl, and muriatic acid by HCl.

II.—IODINE.

Iodine is a solid substance of a lead grey colour, which, when heated, is converted into a beautiful violet vapour. It exists in combination chiefly with sodium, as *Iodide of Sodium*, in sea water and in marine plants; but it has not hitherto been detected in any of the crops usually raised for food.

Like chlorine, it is poisonous both to animals and plants; and was found by Davy to assist and hasten germination. It may possibly exert some hitherto unobserved influence upon vegetation, when it is applied to the soil in districts where sea-ware is largely collected and employed as a manure.

Iodine is slightly soluble in water, and this solution has been mentioned in a previous lecture (VI. p. 156), as affording a ready means of detecting starch by the beautiful blue colour it gives with this substance.

III.—SULPHUR, SULPHUROUS AND SULPHURIC ACIDS, AND SULPHURETTED HYDROGEN.

1°. *Sulphur* is a substance too well known to require any detailed description. In an uncombined state it occurs chiefly in volcanic countries, but it may sometimes be observed in the form of a thin pellicle on the surface of stagnant waters—or of mineral springs, which are naturally charged with sulphurous vapours. In this state it is not known materially to influence the natural vegetation in any part of the globe. It has, however, been employed with

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salt, and in one of the processes immense quantities of muriatic acid are given off from the furnace, and used to escape into the air by the chimney.

some advantage in Germany as a top-dressing for clover and other crops to which gypsum in that country is generally applied. The mode in which it may be supposed to act will be considered hereafter.*

2°. *Sulphurous acid.*—When sulphur is burned in the air it gives off a gaseous substance in the form of white fumes of a well known intensely suffocating odour. These fumes consist of a combination of the sulphur which disappears with the oxygen of the atmosphere, and are known to chemists by the name of sulphurous acid. This compound is destructive to animal and vegetable life, but as it is not known to be directly formed to any extent in nature, except in the neighbourhood of active volcanoes, it probably exercises no extensive influence on the general vegetation of the globe.

This gas possesses the curious property of bleaching many animal and vegetable substances. Wool and straw for plaiting are bleached to an almost perfect whiteness—when they are suspended in a vessel or room into which a plate of burning sulphur has been introduced. Gardeners sometimes amuse themselves also in bleaching roses and other red flowers, by holding them over a burning sulphur match. Some shades of red resist this action more or less perfectly, and the colour of the bleached flowers may often be restored—by dipping them in a dilute solution of carbonate of soda, or by holding them over a bottle of hartshorn (liquid ammonia).

3. *Sulphuric acid.*—This is the name by which chemists distinguish the *oil of vitriol* of the shops. It is also a compound of sulphur and oxygen only, and is formed by causing the fumes of sulphur to pass into large leaden chambers along with certain other substances, from which they can obtain a further supply of oxygen.

It is met with in the shops in the form of an exceedingly sour corrosive liquid, which decomposes, chars, and destroys all animal and vegetable substances, and, except when very diluted, is destructive to life in every form. It is rarely met with in nature, in an uncombined state,—though according to Boussingault, some of the streams which issue from the volcanic regions of the Andes, are rendered sour by the presence of a quantity of this acid.

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* The refuse heaps of the alkali works on the Tyne, contain much sulphur and more gypsum—but the farmers, perhaps, naturally enough, consider that if the works themselves do harm to their crops, the refuse of the works cannot do them much good. There are thousands of tons of this mixture which may be had for the leading away.

It combines with potash, soda, lime, magnesia, &c., and forms *sulphates* which exist abundantly in nature, and have often been beneficially and profitably employed as manures.

Where the soil contains lime or magnesia, the acid may often be applied directly to the land, in a *very* dilute state, with advantage to clover and other similar crops. It has in France, near Lyons, been observed to act favourably when used in this way, while in Germany it has been found better to apply it to the ploughed land, previous to sowing. A few experiments have also been made in this country with partial success. It is deserving, however, of a further trial, and in more varied circumstances.

4°. *Sulphuretted Hydrogen.*—This gaseous compound of sulphur with hydrogen, is almost universally known by its unpleasant smell. It imparts their peculiar taste and odour to sulphurous springs, such as that of Harrogate, and gives their disagreeable smell to rotten eggs. It is often produced in marshy and stagnant places,* and fish ponds, where vegetable matter is undergoing decay in the presence of water containing gypsum, or other *sulphates* ; and it may occasionally be detected by the sense of smell among the roots of the sod, in old pasture land, to which a top-dressing is occasionally given.

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* This appears to be especially the case on the coasts of Western Africa, where the hot sun is continually beating on sea water, often shallow, frequently stagnant, and always laden with organic matter, either animal or vegetable (Daniell). Near the mouth of the Tees in this county, where a shallow, dark blue, muddy, samphire-bearing tract stretches for several miles inland from Seaton Snook, the presence of sulphuretted hydrogen may be perceived by the smell, when on a hot summer's day a gentle air skims along the edge of the Slake. The favourable conditions are, a burning sun, a very gentle air, and such a condition of the sea—that those parts and pools which are only reached by the spring tides, shall have been several days uncovered.

As in the egg, so also in other decaying animal substances, especially when the air is in some measure excluded, this gas is formed. In putrified cow's urine, and in night-soil, it is present in considerable quantity.

Sulphuretted hydrogen is exceedingly noxious to animal and vegetable life, when diffused in any considerable quantity through the air, by which they are surrounded. The luxuriance of the vegetation in the neighbourhood of sulphurous springs, however, has given reason to believe that water impregnated with this gas, may act in a beneficial manner when it is placed within reach of the roots of plants. It seems also to be ascertained that natural or artificial waters which have a sulphurous taste, give birth to a peculiarly luxuriant vegetation, when they are employed in the irrigation of meadows.*

The relative constitution of these three compounds of sulphur, is thus represented:—

One equivalent of	Weighing	Is represented by	Or one of Sulphur and
Sulphur	16	S	
Sulphurous Acid . . .	32	SO_2	2 of Oxygen
Sulphuric Acid	40	SO_3	3 of Oxygen
Sulphuretted Hydrogen	17	SH	1 of Hydrogen.†

IV.—PHOSPHORUS AND PHOSPHORIC ACID.

1°. *Phosphorus* is a solid substance of a pale yellow colour, and of a consistence resembling that of wax. When exposed to the air it slowly combines with the oxygen of the atmosphere, and burns away with a pale blue flame visible only in the dark. When rubbed, however, or exposed to a slight elevation of temperature, even to the heat of the hand, it readily bursts into a brilliant flame, emitting an intense light accompanied by dense white vapours. It does not occur in nature in an uncombined state, and is not known to be susceptible of any useful application in practical agriculture.

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* Sprengel *Chemie* I., p. 355.

† For the properties of oxygen and hydrogen see above page 24, and for their equivalent or atomic weights see page 40.

2°. *Phosphoric Acid.*—The white fumes given off by phosphorus, or rather into which it is changed, when burned in the air or in oxygen gas, consist of phosphoric acid. This compound is solid and colourless, attracts moisture from the air with great rapidity, is exceedingly soluble in water, has an intensely sour taste, and like sulphuric acid is capable of corroding and destroying animal and vegetable substances.

It does not exist in nature in a free state, and, therefore, is not *directly* influential upon vegetation. It unites, however, with potash, soda, lime, &c., to form compounds, known by the name of *phosphates.* In these states of combination, it is almost universally diffused throughout nature—and appears to be essentially necessary to the healthy growth and maturity of all living—certainly of all cultivated vegetables.

V.—POTASSIUM, POTASH, CARBONATE, SULPHATE, OXALATE, TARTRATE, CITRATE, AND SULPHATE OF POTASH, AND CHLORIDE OF POTASSIUM.

1°. *Carbonate of Potash.*—In countries where non-resinous trees abound, it is usual to burn the wood which cannot otherwise be employed—as in the clearings in Canada and the United States—for the purpose of collecting the ash which remains. This ash is washed with water and the washings boiled to dryness in iron pots. In this state it forms the *pot*-ash of commerce. When this potash is again dissolved in water, and the clear liquid decanted and boiled, the *pearl*-ash of the shops is obtained.

This pearl-ash is an impure form of the *carbonate* of potash of chemists. It readily dissolves in water, has a peculiar taste—distinguished as an *alcaline* taste—and dissolves in vinegar or in diluted sulphuric or muriatic acid, with much *effervescence.* The gas given off during this effervescence (or boiling up) is carbonic acid, the same which, as was shewn in a previous lecture, is obtained, when a diluted acid is poured upon chalk or common limestone.

This carbonate of potash has been long known to exercise a powerful influence over the growth of plants.

The use of wood-ash as a fertilizer both of pasture and of arable land, goes back to the most remote antiquity; and though the crude wood-ash contains other substances also, yet much of its immediate and most apperent effect is due to the carbonate of potash it contains.

From what has already been stated, at the commencement of the present lecture, in regard to the presence of potash in the parts and juices of nearly all plants, you will already in some measure understand why the carbonate of potash should be useful to vegetation, and—since this alkali (potash) is present in greater quantity in some, than in others —why it should appear to be more especially favourable to the growth of one kind of plant than of another.

In this way, it is explained why moss and coarse grasses are extirpated from meadows by a sprinkling of wood ashes —and why red clover, lucerne, esparsette, beans, peas, flax, and potatoes, &c., are greatly promoted in their growth by a similar treatment. This substance, however, has other functions to perform in reference to vegetation, besides that of simply supplying the crop with the potash it requires; these functions I shall explain more particularly hereafter, when you will perhaps be better prepared for understanding the details into which it will be necessary to enter.

2°. *Potash.*—When 12 parts of carbonate of potash are dissolved in water, and boiled with half their weight of newly-slaked quicklime, they are gradually deprived of their carbonic acid, and converted into pure potash,—or as it is often called, from its effect on animal and vegetable substances, *caustic potash.*

The caustic liquid thus obtained decomposes or dissolves most animal and vegetable substances, whether living or dead. When applied to the skin, unless it be in a very diluted state, it destroys it, and produces a painful sore. Potash does not occur in nature in this caustic or uncombined state, and is not known, therefore, to exercise any *direct* influence upon natural vegetation.

When wood-ashes and quick-lime are mixed together in artificial composts, it is not unlikely that a portion of the carbonate of potash may be rendered caustic, and, therefore, be more fit to act upon the vegetable matter in contact with it—by rendering it soluble in water and thus capable of entering into the roots of plants. To this point I shall have occasion to return hereafter. In the mean time, it is proper to remark, that if pearl-ash be mixed, as above prescribed, with half its weight of quick-lime, and then boiled with *less than ten or twelve times its weight of water, a part of the potash only is rendered caustic*—the lime being unable to deprive the pearl-ash (carbonate of potash) of its carbonic acid, unless it be largely diluted. Hence, in dry composts, or mixtures of this substance with quick-lime, it is unlikely that any large portion of the potash can be at once brought to the caustic state. This fact is really of importance in reference to the theory of the conjoined action of quick-lime and wood or pearl-ash, when mixed together in artificial manures, and applied to the land.

3°. *Potassium.*—When dry caustic potash, obtained by evaporating the caustic solution above described, is mixed with powdered charcoal and iron filings, and exposed to an intense heat in an iron retort, it is decomposed, and metallic *potassium* distils over, and is collected in the form of white shining silvery drops.

It was one of the most remarkable discoveries of Sir H. Davy, that potash was a compound substance, and consisted of this metal potassium united to oxygen gas.

Potassium is remarkable for the strong tendency it possesses to unite again with oxygen and re-form potash. When simply exposed to the air, it gradually absorbs oxygen from the atmosphere; but if it be heated in the air, it takes fire and burns. When the combustion has ceased, a quantity of *caustic* potash remains, the weight of which is nearly one-fifth greater than that of the potassium employed. It even bursts into a flame when thrown upon water, depriving that liquid of its oxygen, and liberating its hydrogen,*—and it was justly considered as the most astonishing property of this metal, when first discovered, that it took fire when placed upon the coldest ice. When thus burned in contact with water, potash is formed, as before, and is found dissolved in the liquid when the experiment is completed.

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* For the composition of water, see Lecture II., p. 42.

4. *Chloride of Potassium.*—This is a compound of chlorine with potassium, which, in taste, properties, and general appearance, has much resemblance to common salt. It may be formed by dissolving pearl-ash in dilute muriatic acid (spirit of salt) as long as any effervescence appears, and afterwards evaporating to dryness. It exists in small quantity in sea water, in the ash of most plants, and frequently in the soil. It is not an article of manufacture, but is occasionally extracted from kelp, and sold to the alum makers. Could it be easily and cheaply obtained, there is no doubt that it might be employed with advantage as a manure, and especially in those circumstances in which common salt has been found to promote vegetation. The refuse of the soap-boilers, where soap is made from kelp, contains a considerable quantity of this compound. This refuse might be obtained at a cheap rate, and, therefore, might be usefully collected and applied to the land where such works are established.

5°. *Sulphate of Potash.*—This compound is formed by adding pearl-ash to dilute sulphuric acid (oil of vitriol) as long as effervescence appears, and then evaporating the solution. It is a white saline substance, sparingly soluble in water, and has a disagreeable bitterish taste. It exists in considerable quantity in wood-ash, and in the ash of nearly all plants, and is one of the most abundant impurities in the common potash and pearl-ash of the shops. This sulphate itself is not an article of extensive manufacture, but it exists in common alum to the amount of upwards of 18 per cent. of its weight.

Dissolved in 100 times its weight of water, the sulphate of potash has been found to act favourably on red clover, vetches, beans, peas, &c., and part of the effect of wood ashes on plants of this kind, is to be attributed to the sulphate of potash they contain. Turf ashes are also said to contain this salt in variable quantity, and to this is ascribed a portion of their efficacy also when applied to the land.

6°. *Nitrate of Potash* or saltpetre is a well known saline substance, of which mention has already been made in the preceding lectures.[*] It contains potash and nitric acid only, and may be readily formed by dissolving pearl-ash in nitric acid, and evaporating the solution. It exists, and is continually reproduced in the soil of most countries, and is well known to exercise a remarkable influence in accelerating, and increasing the growth of plants.

7°. *Oxalates of Potash.*—These salts exist in the common and wood sorrels, and in most of the other more perfect plants in which oxalic acid is known to exist.[†] The *salt of sorrel* is the best known of these oxalates. This salt has an agreeable acid taste, and is not so poisonous as the uncombined oxalic acid.

When this salt is heated over a lamp, the oxalic acid it contains is decomposed, and carbonate of potash is obtained. It is supposed that a great part of the potash extracted from the ashes of wood and of the stems of plants in general, in the state of carbonate, existed as an oxalate in the living tree, and was converted into carbonate during the combustion of the woody fibre and other organic matter. This compound, therefore, in all probability, performs an important part in the changes which take place in the interior of plants, though its direct agency in affecting their growth when applied externally to their roots, has not hitherto been distinctly recognised. It is probably formed occasionally in farm-yard manure, and in decaying urine and night-soil, but nothing very precise is yet known on this subject.

8°. *Citrates and Tartrates of Potash.*—These salts exist in many fruits. The citrates abound in the orange, the lemon, and the lime—the tartrates in the grape. When heated over a lamp, they are decomposed, and like the oxalates leave the potash in the state of carbonate.

In the interior of plants, both potash and soda are most frequently combined with organic acids (oxalic, citric, tartaric, &c.[‡]) and the compounds thus formed are generally what chemists call *acid* salts—that is to say, they generally have a distinctly sour taste, redden vegetable blues, and contain much more acid than is found to exist in certain other well known compounds of the same acids with potash.

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[*] See p. 75 and pp. 237 to 245.

[†] See pp. 61 and 204.

[‡] For an account of the most abundant organic acids, see lecture VI., p. 178.

The citrates and tartrates are not known to be formed in nature, except in the living plant, and as they are too expensive to be ever employed as manures, it is the less to be regretted that few experiments have yet been tried with the view of ascertaining their effect upon vegetation.

9°. *Phosphates of Potash.*—If to a known weight of phosphoric acid (p. 274) pearl-ash (carbonate of potash) be added as long as any effervescence appears, and the solution be then evaporated, *phosphate* of potash is obtained. If to the solution before evaporation a second portion of phosphoric acid be added, equal to the first, and the water be then expelled by heat, BI-*phosphate*[*] of potash will remain.

One or other of these two salts is found in the ash of nearly all plants. Whether or not the elements of which they consist exist in this state of combination in the living plant will be considered hereafter, in the mean time it may be stated as certain that they are of the most vital importance not only in reference to the growth of plants themselves, but also to their nutritive qualities when eaten by animals for food.

These phosphates are occasionally, perhaps very generally, present in the soil in minute quantities, and there is every reason to believe that could they be applied to the land in a sufficiently economical form, they would in many cases act in a most favourable manner upon vegetation. They are contained in urine and other animal manures, and to their presence a portion of the efficacy of these manures is to be ascribed.

VI.—SODIUM, SODA, CARBONATE OF SODA, SULPHATE OF SODA, PHOSPHATE OF SODA, SULPHURET OF SODIUM, CHLORIDE OF SODIUM.

1°. *Chloride of Sodium,* common or sea salt, exists abundantly in sea water, and is found in many parts of the earth in the form either of incrustations on the surface or of solid beds or masses at considerable depths. The rock salt of Cheshire is a well known example of this latter mode of occurrence,

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[*] So called from *bis*, twice, because it contains *twice* as much acid as the former, or *neutral* phosphate.

Common salt may also be detected in nearly all soils, it is found in the ashes of all plants, but especially and in large quantity in the ashes of marine plants (Kelp), and is sometimes borne with the spray of the sea to great distances inland, when the winds blow strong, and the waves are high and broken.

On some rocky shores, as on that between Berwick and Dunbar, the spray may be seen occasionally moving up the little coves and inlets in the form of a distinct mist driving before the wind, and the saline matter has been known to traverse nearly half the breadth of the island before it was entirely deposited from the air.

It is impossible to calculate how much of the saline matter of sea water may in this way be spread over the surface of a sea-girt land like ours; but two things are certain—that those places which are nearer the sea will receive a greater, and those more inland a lesser, portion; and that those coasts on which sea winds prevail will be more largely and more frequently visited than those on which land winds are more commonly experienced.

It is well known that common salt has been employed in all ages and in all countries for the purpose of promoting vegetation, and in no country perhaps in larger quantity or more extensively than in England. That it has often failed to benefit the land in particular localities, only shows that the soil in those places already contained a natural supply of this compound large enough to meet the wants of the crops which grew upon it. The facts above stated as to the influence of the wind in *top-dressing* the exposed coast-line of a country with a solution of salt, may serve as an important guide both in reference to the places in which it may be expected to benefit the land, and to the causes of its failing to do so in particular districts.

2°. *Sulphate of Soda*, or Glauber's salt, is usually manufactured from common salt by pouring upon it diluted sulphuric acid (oil of vitriol), and applying heat. Muriatic acid (spirit of salt*) is given off in the form of vapour, and sulphate of soda remains behind. It may also be prepared, though less economically, by adding the common soda of the shops to diluted sulphuric acid as long as any effervescence appears.

This well known salt is met with in variable quantity in the ashes of nearly all plants, and is diffused in minute proportion through most soils. I have elsewhere† directed your attention to the beneficial effect which it has been observed to exercise on the growth especially of such plants as are known to contain a considerable proportion of sulphuric acid. Among these are red clover, vetches, peas, &c. And as this salt is manufactured largely in this country, and can be obtained at the low price of ten shillings a cwt. in the dry state,‡ I have recommended it to the practical farmer as likely to be extensively useful as a manure for certain crops and on certain soils. The kind of crops and soils have as yet in great measure to be determined by practical trials.§

3°. *Sulphuret of Sodium.*—When sulphate of soda is mixed with saw-dust, and heated in a furnace, the oxygen of the salt is separated, and sulphuret of sodium is produced. By a similar treatment sulphate of potash is converted into sulphuret of potassium. These compounds consist of sulphur and metallic sodium or potassium only. They do not occur extensively in nature, and are not manufactured for sale; but there is reason to believe that they would materially promote the vegetation of such plants, as contain much sulphur in combination with potash or soda. The sulphuret of sodium is present in variable quantity in the refuse lime of the alkali works, already spoken of, and might be expected to aid the other substances of which it chiefly consists, in contributing to the more rapid growth of pulse and clover crops.

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* So called by the old chemists, because thus given off by common salt.

† See Appendix, page 2.

‡ Not in crystals, the form in which it is commonly sold as a horse medicine. These crystals contain upwards of half their weight (55 per cent.) of water.

§ See the results of Mr. Fleming's Experiments, Appendix, p. 27, et sequent.

4°. *Carbonate of Soda.*—I have described the above compounds of soda before mentioning this its best known and most common form, because they are all steps in the process by which the latter is usually prepared from common salt, by the soda manufacturers.

When the sulphuret of sodium is mixed with chalk in certain proportions, and heated in a furnace, it is deprived of its sulphur, and is converted into *carbonate* of soda, the common soda of the shops.

This well known salt, now sold in the state of crystals* at from 10s. to 12s. a cwt., has not as yet been extensively tried as a means of promoting vegetation. The lowness of its price, however, and the fact that it is an article of extensive home manufacture, conjoined with the encouragement we derive from theoretical considerations—all unite in suggesting the propriety of a series of experiments with the view of determining its real value to the practical agriculturists. The mode in which theory indicates that this compound is likely to act in promoting vegetation—as well as the crops to which it may be expected to be especially useful, will come under our consideration hereafter.

Besides the common carbonate of soda above described, and which in the neighbourhood of Newcastle is manufactured from common salt to the amount of 30 or 40 thousand tons every year, there occur in nature two other compounds of soda with carbonic acid, in which the latter substance is present in larger quantity than in the soda of the shops. The *sesqui*-carbonate, containing one half more carbonic acid, occurs in the soil in many warm climates (Egypt, India, South America, &c.), and at Fezzan, in Africa, is met with as a mineral deposit of such thickness as in that dry climate to allow of its being employed as a building stone.

The *bi*-carbonate is contained in the waters of many lakes, in Hungary, in Asia, &c., and in many springs in all parts of the world. There can be no doubt that the waters of such springs are fitted to promote the fertility, especially of pasture land, to which they may be applied either by artificial irrigation, or by spontaneous overflow from natural outlets. Some of the Harrowgate waters contain a sensible quantity of this bicarbonate, and over a large portion of the Yorkshire coal-field, a bed of rock is found, at various depths, the springs from which hold in solution a considerable portion of this salt. The Holbeck water of Leeds, according to Mr. West, owes its softness to the presence of this carbonate, and the water from the coal-mines in the neighbourhood of Wakefield, is occasionally so charged with it, as to form troublesome saline incrustations on the bottoms of the steam boilers. Where these waters occur in sufficient abundance, they should not be permitted to escape into the rivers, until they have previously been employed in irrigating the land.

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* Containing 62 per cent. of water.

It has occasionally been observed that natural springs in some localities impart a degree of luxuriance to natural pasture, which is not to be accounted for, by the mere effect of a constant supply of water. In such cases, the springs may be expected to contain some alcaline, or other mineral ingredient, which the soil is unable to supply to the plants which grow upon it, either in sufficient abundance, or with sufficient rapidity.

5°. *Soda or Caustic Soda.*—When a solution of the common soda of the shops is boiled with quick-lime, it is deprived of its carbonic acid, and like the carbonate of potash (p. 275) is brought into the *caustic* state. In this state, it destroys animal and vegetable substances, and, unless very dilute, is injurious to animal and vegetable life.

When common salt (chloride of sodium) is mixed with quicklime in compost heaps, it is deprived by the lime of a portion of its chlorine, and is partially converted into this caustic soda. The action of the soda in this state is similar to that of caustic potash. Not only does it readily supply soda to the growing plant, to which soda is necessary, but it also acts upon certain other substances which the plants require, so as to render them soluble, and to facilitate their entrance into the roots of plants. To the presence of soda in this caustic state, the efficacy of such composts of common salt and lime in promoting vegetation, is in part to be ascribed.

6°. *Sodium* is a soft metal of a silver white colour, and, like potassium, light enough to float upon water. It is obtained by heating caustic soda with a mixture of charcoal and iron filings. It takes fire upon water—though not so readily as potassium—and combines with its oxygen to form soda. In the metallic state it is not known to occur in nature, and, therefore, does not directly act upon vegetation. With oxygen it forms soda,—with chlorine, chloride of sodium (common salt),—and with sulphur, sulphuret of sodium,—all of which, as already stated, are more or less beneficial to vegetation.

7°. *Phosphates of Soda.*—When the common soda of the shops is added to a solution of phosphoric acid in water, till effervescence ceases, and the solution is evaporated to dryness, phosphate of soda is formed, and by the subsequent addition of as much more phosphoric acid—*bi*-phosphate. These salts occur more or less abundantly in the ash of nearly all plants; they are occasionally also detected in the soil, and one or other of them is almost always present in urine and other animal manures. As we know from theory, that these compounds must be grateful to plants, we are justified in ascribing a portion of the efficacy of animal manures, in promoting the growth of vegetables, to the presence of these phosphates, as well as to that of the phosphates of potash (p. 279). They are not known to occur in the mineral kingdom in any large quantity, neither are they articles of manufacture, hence their direct action upon vegetation has not hitherto been made the subject of separate experiment.

VII.—CALCIUM, LIME, CARBONATE OF LIME, SULPHATE OF LIME, NITRATE OF LIME, PHOSPHATES OF LIME, CHLORIDE OF CALCIUM, SULPHURET OF CALCIUM.

1°. *Carbonate of Lime.*—Chalk, marble, and nearly all the limestones in common use, are varieties, more or less pure, of that compound of lime with carbonic acid, which is known to chemists as carbonate of lime. It occurs of various colours and of various degrees of hardness, but in weight the compact varieties are very much alike, being generally a little more than 2½ times (2·7) heavier than water. They all dissolve with effervescence in dilute muriatic acid (spirit of salt), and by the bubbles of gas which are seen to escape when a drop of this acid is applied to them, limestones may in general be readily distinguished from other varieties of rock. They dissolve slowly also in water which holds carbonic acid in solution; and hence the springs which issue from the neighbourhood of deposits of limestone are generally charged in a high degree with this mineral substance.

The value of this carbonate of lime in rendering a soil capable of producing and sustaining a luxuriant vegetation depends, in part, it is true, on the necessity of a certain proportion of lime to the growth and full development of the several parts of nearly all plants, but it performs also other important offices, which we shall hereafter have occasion more fully to consider.

2°. *Lime or Quick-lime.*—When limestone is burned along with coal or wood in kilns so constructed that a current of air can pass freely through them, the carbonic acid is driven off, and the lime alone remains. In this state it is generally known by the name of burned or *quick*-lime, from its caustic qualities, and is found to have lost nearly 44 per cent. of its original weight.

The most remarkable property of quick-lime is its strong tendency to combine with water. This is displayed by the eagerness with which this liquid is drunk in by the lime in the act of slaking, and by the great heat which is at the same time developed. Slaked lime is a compound of lime with water, and by chemists is called a *hydrate* of lime. It contains 24 per cent. of its weight of water.

The action of quick-lime upon the land is one of the most important which presents itself to the observation of the practical agriculturist. Among other effects produced by it is that of hastening the decomposition of vegetable matter either in the soil or in compost heaps; but this effect is materially promoted by—if it be not wholly dependent upon—the presence of air and moisture. By this decomposition carbonic acid and other compound substances are produced, which the roots are capable of absorbing and converting into the food of plants.

In this caustic state lime does not occur in nature, nor when exposed to the air does it long remain in this state. It gradually absorbs carbonic acid from the atmosphere, and is again converted into carbonate. This change takes place more or less rapidly in all cases where quick-lime is applied to the land, but the benefits arising from burning the lime do not disappear when it is thus reconverted into carbonate. On the contrary, the state of very fine powder, into which quick-lime falls on slaking, enables the carbonate of lime, subsequently formed, to be intermixed with the soil in a much more minute state of division than could be obtained by any mechanical means. This we shall hereafter see to be a most important fact, when we come to study in more detail the theory of the action of lime in the several states of combination, and under the varied conditions in which it is employed for the purpose of improving the land.

3°. *Calcium* is a silver-white metal, which, by its union with oxygen, forms *lime*. It is not known to exist in nature in an uncombined state, is prepared artificially only with great difficulty, and therefore exercises no direct action on vegetable growth.

4°. *Chloride of Calcium.*—When chalk or quick-lime is dissolved in muriatic acid, a solution of *chloride of calcium* is obtained. This solution occurs in sea-water, in the refuse (mother liquor) of the salt-pans, and is allowed to flow away in large quantities as a waste from certain chemical works. I have elsewhere* stated the effects it has been observed to produce upon vegetable growth, and have recommended the propriety of making experiments with the view of rendering useful some of those materials which in our manufactories are now suffered largely to run to waste.

5°. *Sulphuret of Calcium* is a compound of sulphur and calcium, which may be formed by heating together chalk and sulphur in a covered crucible. It is sometimes produced in nature, where moist decaying vegetable and animal matters are allowed to ferment in the presence of gypsum; it may sometimes also be detected in the soil, and in the waters of mineral springs, and is contained largely in the recent refuse heaps of the alkali works. Like the sulphurets of potassium and sodium, already described, it is fitted, when judiciously applied, to promote the growth especially of those plants in which sulphur has been recognised as a necessary constituent.

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* See Appendix, p. 15.

6°.—*Sulphate of Lime*, or gypsum, is a well-known white crystalline or earthy compound, which occurs as an abundant mineral deposit in numerous parts of the globe. It is present in many soils, is contained in the waters which percolate through such soils, and in those of springs which ascend from rocky beds in which gypsum exists, and is detected in sensible proportions in the ashes of many cultivated plants. It is extensively employed in the arts, and in some countries not less extensively as a means of promoting the fertility of the land.*

The gypsum of commerce contains nearly 21 per cent. of its weight of water, which it loses entirely on being exposed to a red heat. In some countries, a variety which is almost entirely free from water occurs in rocky masses, and is distinguished by the name of *Anhydrite*.

Gypsum, when burned, has the property of being reduced with great ease into the state of an impalpable powder. This powder, however, combines so readily with the 21 per cent. of water it had previously lost, that if it be mixed with water to the consistence of a paste so thin that it can be poured into a mould, it sets and hardens in a few minutes into a solid mass. In this way burned gypsum is employed in making plaster casts and cornices.

Burned gypsum consists of lime and sulphuric acid only —in the proportions of 41½ of the former, to 58½ of the latter. Its use as a manure, therefore, will be specially to promote the growth of those plants by which these two substances are more abundantly required, and upon soils in which they are already present in comparatively small proportion.

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* See Appendix, p. 1.

7°. *Nitrate of Lime.*—The production of nitrate of lime in artificial nitre-beds, on old walls, and on the sides of caves and cellars, especially in damp situations, has already been alluded to in a previous lecture.* It may be formed artificially by dissolving common limestone in nitric acid, and evaporating the solution. It constitutes a white mass which rapidly attracts water from the air, and runs to a liquid. It is produced naturally, and exists, as I believe, in soils containing lime, more commonly than has hitherto been suspected. Its extreme solubility in water, however, renders it liable to be carried downwards into the lower portions of the soil by every shower of rain—or to be actually washed away, when long continued wet weather prevails.

When heated to dull redness with vegetable matter, the nitrate of lime is decomposed, and is converted into carbonate, or when exposed alone to a bright red heat, the nitric acid is expelled, and quick-lime alone remains. Hence where it really exists in plants, it cannot be detected in the ash,—and when present in soils, it must be separated by washing them in water, before they are exposed to a heat sufficient to burn away the organic matter they contain.

The details already entered into in the preceding lecture (pp. 237 and 245) regarding the general action of nitric acid, in promoting the natural vegetation of the globe, render it unnecessary for me to dwell here on the special action of its compound with lime—more particularly as the entire subject of the action of lime upon the land will hereafter demand from us a separate consideration.

The nitrate of lime cannot, as yet, be formed by art, at a sufficiently cheap rate to allow of its being manufactured for the use of the agriculturist.

Phosphates of Lime.—Lime combines with phosphoric acid in several proportions, forming as many different compounds. Of these by far the most important and abundant in nature—

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* Lecture VIII., p. 242.

certainly the most useful to the agriculturist, is the *earth of bones*. It will be necessary, however, to advert shortly to two others, with the existence of which it is important for us to be acquainted.

A. *Earth of Bones* is the name given to the white earthy skeleton that remains, when the bones of animals are burned in an open fire until every thing combustible has disappeared. This earthy matter consists chiefly of a peculiar phosphate of lime, composed of 51½ per cent. of lime, and 48½ of phosphoric acid. This compound exists ready formed in the bones of all animals, and is the substance selected in the economy of nature, to impart to them their strength and solidity. It is found in smaller quantity in those of young animals, while they are soft, and cartilaginous,—and the softening of the bones, which in after-life occurs as the result of disease, is caused by the unnatural abstraction of a greater portion of this earthy matter, than is replaced by the food.

This earthy phosphate constitutes about 57 per cent. of the dried bones of the ox, is present in lesser quantity in the horns, hoofs and nails, and is never absent even from the flesh and blood of healthy animals. It exists in the seed of many plants, in all the varieties of grain which are extensively cultivated for food, and in the ashes of most common plants. The ashes of leguminous, cruciferous, and composite plants, are especially rich in this compound.

If we consider that when animals die, their bones are chiefly buried in the earth, and that over the entire globe, animal life, in one or other of its forms, prevails, we shall not be surprised that, in almost every soil, the earth of bones should be found to exist in greater or less abundance. Nor can we have any difficulty in conceiving, if such be the case, whence plants draw their constant and necessary supplies of this substance.

At the same time, it is true of this compound, as of all the others we have yet spoken of, as occurring in, and as necessary to the growth of vegetables,—that some soils contain it in greater abundance than others, and that from some soils, therefore, certain plants will not readily obtain as much of this substance as they require. This is the natural principle on which the use of bone-dust as a manure chiefly depends.

Hence of two marls both containing carbonate of lime—that will be most useful to the land which contains also, as many do, a notable portion of phosphate of lime ; and of two limestones, that will be preferred in an agricultural district in which animal remains most abound. I shall have occasion to illustrate this point more fully, when in a subsequent lecture I come to explain the natural origin of soils, and to trace their chemical constituents to the several rocky masses from which they appear to have been derived.

Before dismissing this topic, however, there are one or two properties of this bone earth which are of practical importance, and to which, therefore, I must shortly request your attention. It is insoluble in water or in solutions of soda or potash, but it dissolves readily in acids, such as the nitric or muriatic, and also, though less easily and abundantly, in common vinegar. It exists in milk, and is supposed to be held in solution by a peculiar acid found in this liquid, and which is distinguished by the name of *lactic acid* (acid of milk).

It is slightly soluble also in a solution of carbonic acid, and of certain other organic acids which exist in the soil, and it is by means of these acids, that it is supposed to be rendered capable of entering into the roots of plants. Wherever vegetable matter exists, and is undergoing decay in the soil, the water makes its way to the roots more or less laden with carbonic acid, and thus is enabled to bear along with it not only common carbonate of lime, as has been shown in a previous lecture (p. 60), but also such a portion of phosphate as may aid in supplying this necessary food to the growing plant.*

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* If to a solution of bone earth in muriatic acid (spirit of salt), liquid ammonia (hartshorn) be added, the solution will become milky, and a white powder will fall, which is the earth of bones in an extremely minute state of division. If this powder be washed by repeated affusions of pure water, and be afterwards well shaken with water which is saturated with carbonic acid, or through which a current of this gas is made to pass, a sensible portion of the phosphate will be found to be taken up by the water. This will appear on decanting the solution and evaporating it to dryness, when a quantity of the white powder

In the bones of animals the phosphate is associated with animal *gelatine*, which can be partially extracted by boiling bones in water under a high pressure. It has been observed, however, that the phosphate, when in a minute state of division, is slightly soluble in a solution of gelatine, and hence bones, from which the jelly has been partially extracted by boiling, will be deprived of a certain proportion of their earthy matter also. They will have lost their gelatine, however, in a greater proportion, and hence, *if again thoroughly dried*, they will contain a larger per-centage of bone earth, than when in their natural state. In this country, bones are seldom boiled, I believe, either for the jelly they give, or as in France and Germany for the manufacture of glue, though in certain localities they are so treated in open vessels for the sake of the oil they are capable of yielding. Such boiled bones are said to act more quickly when applied to the land, but to be less permanent in their effects. This may be chiefly owing to their not being so perfectly dry as the unboiled bones. Being thus moist they will contain, in the same weight, a comparatively smaller quantity both of the animal gelatine, and of the earthy phosphate, while they will also be more susceptible of speedy decomposition, when buried in the soil.*

In solutions of common salt and of sal-ammoniac, the earth of bones is also slightly soluble, and cases may occur where the presence of these compounds in the soil may facilitate the conveyance of the earthy phosphate into the roots of plants.

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will remain behind. The mean of 10 experiments made in this way gave me 30 grains for the quantity of phosphate taken up by an imperial gallon of water. What takes place in this way in our hands, happens also in the soil. Not only does that which enters the root bear with it a portion of this compound where it exists in the soil, but the superabundant water also which runs off the surface or sinks through to the drains, carries with it to the rivers in its course, a still larger quantity of this soluble compound, and thus gradually lessens that supply of phosphate which either exists naturally in the soil, or has been added as a manure by the practical agriculturist.

* The relative value of crushed bones in these two states, is indicated by the price of the unboiled being about 7 guineas, while that of boiled is only about 4 guineas a ton.

B. *Acid or* Bi-*Phosphate of Lime.*—When burned bones are reduced to powder, and digested in sulphuric acid (oil of vitriol), diluted with once or twice its weight of water, the acid combines with a portion of the lime, and forms sulphate of lime (gypsum), while the remainder of the lime, and the whole of the phosphoric acid are dissolved. The solution, therefore, contains an *acid* phosphate of lime, or one in which the phosphoric acid exists, in much larger quantity than in the earth of bones. The true bi-phosphate, when free from water, consists of 71¼ of phosphoric acid, and 28¾ of lime. It exists in the urine of most animals, and is, therefore, an important constituent of liquid manures of animal origin.

If the mixture of gypsum and acid phosphate, above described, be largely diluted with water, it will form a most valuable liquid manure, especially for grass land, and for crops of rising corn. In this liquid state, the phosphoric acid will diffuse itself easily and perfectly throughout the soil, and there will speedily lose its acid character by combining with one or other of the *basic** substances, almost always present in every variety of land.

Or if, to the solution before it is applied to the land, a quantity of pearl-ash be added until it begin to turn milky, a mixture of the phosphates with the sulphates of lime and of potash will be obtained, or—if soda be added instead of potash—of the phosphates with the sulphates of lime and of soda; either of which mixtures will be still more efficacious upon the land, than the solution of the acid phosphates alone.

Or to the solution of bones in the acid, the potash or soda may be added without further dilution, and the whole then dried up by the addition of charcoal powder, or even of vegetable mould, till it is in a sufficiently dry state to be scattered with the hand as a top-dressing, or buried in the land by means of a drill.

I have above alluded to the employment of bones in France and Germany, for the manufacture of glue. For this purpose, the broken bones are digested in weak muriatic acid, by which the earthy matter is dissolved, and the gelatine left behind. The gelatinous skeleton is boiled down for glue, and the solution of the bone earth is thrown away. This solution contains a mixture of the *acid* phosphate of lime, with chloride of calcium,—and might be used up in any of the ways above described, with manifest benefit to the land. The glue prepared by this method, however, is said to be inferior in quality, and as the process is not adopted in this country, the opportunity of making an economical application of this waste material, is not likely to be often presented to the English farmer.

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* This word has already been used and explained—it is applied to potash, soda, ammonia, lime, magnesia, and other substances, which have the property of combining with acids (sulphuric, nitric, &c.) and of thus *neutralizing* them, or depriving them of their acid qualities and effects.

C. *Native Phosphate of Lime or Apatite.*—In some parts of the world, a hard mineral substance, commonly known by the name of Apatite, occurs in considerable quantity. It consists chiefly of a phosphate of lime, which differs but slightly in its constitution from the earth of bones,—containing 54½ per cent. of lime, while the latter contains only 51½ per cent. The composition of this mineral would lead us to expect it to possess a favourable action upon vegetation, and this anticipation has been confirmed by some experiments made with it on a limited scale by Sprengel.*

It occurs occasionally in mineral veins, especially such as are found in the granitic and slate rocks. Masses of it are met with in Cumberland, in Cornwall, in Finland, in the iron mines of Arendahl in Norway, and in many other localities. A variety of it distinguished by the name of *phosphorite* is said to form beds at Schlachenwalde in Bohemia, and in the province of Estremadura in Spain. From the last of these localities being the most accessible, the time may come when the high price of bones may induce our enterprising merchants to import it—for the purpose of being employed in a finely powdered state as a fertilizer of the land.

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* Sprengel, *Chemie* I., p. 64.

LECTURE X.

Inorganic constituents of plants continued. Magnesia, Alumina, Silica, and the Oxides of Iron and Manganese. Tabular view of the constitution of the inorganic substances described. Proportions in which these several substances are found in the plants cultivated for food. Extent to which these plants exhaust the soil of inorganic vegetable food. State in which the inorganic elements exist in plants.

§ 1. *Inorganic constituents of plants continued.*

VIII.—MAGNESIUM, MAGNESIA, CARBONATE, SULPHATE, NITRATE, AND PHOSPHATE OF MAGNESIA, CHLORIDE OF MAGNESIUM.

1°. *Carbonate of Magnesia* is a tasteless earthy compound, which in some parts of the world forms rocky masses and veins of considerable height and thickness. It occurs more largely, however, in connection with carbonate of lime in the magnesian limestones, so well known in the eastern and northern parts of England,—and in similar rocks, distinguished by the name of *dolomites* or of dolomitic limestones, in various countries of Europe. The pure, exceedingly light, white magnesia of the shops, is partly extracted from the magnesian limestone, and partly from the mother liquor of the salt pans, which generally contains much magnesia.

When pure and dry, carbonate of magnesia consists of $43\frac{1}{3}$ of magnesia, and $51\frac{2}{3}$ of carbonic acid. It dissolves readily in diluted acids (sulphuric, muriatic, and acetic), the carbonic acid at the same time escaping with effervescence.

Existing as it does in many solid rocks, this carbonate of magnesia may be expected to be present in the soil, and it is found in the ashes of many plants. Of the ashes of some parts of plants it constitutes one-sixth of the entire weight.

When exposed to the air in a finely divided state, it gradually absorbs a quantity of moisture from the atmosphere, equal to two-thirds of its own weight. In this state, it dissolves in 48 times its weight of water, though, when dry, it is nearly insoluble. Like carbonate of lime it is also soluble in water impregnated with carbonic acid, but in a somewhat greater degree. In this state of solution, it may be readily carried into the roots, and be the means of supplying to the parts of living vegetables a portion of that magnesia which is necessary to their perfect growth.

Soils containing much of this carbonate of magnesia, are said to be highly absorbent of moisture, and to this cause is ascribed the *coldness*[*] of such soils. This opinion is, however, open to doubt.

2°. *Magnesia or Caustic Magnesia, the calcined magnesia of the shops.*—When the carbonate of magnesia is heated to redness in the open air, it parts with its carbonic acid much more readily than lime does, and is brought into the state of pure or caustic magnesia. In this state it does not occur in nature, but it is occasionally met with in combination with about 30 per cent. of water. When magnesian limestones or dolomites are burned, the quick-lime obtained often contains caustic magnesia also in considerable quantity. This mixture is frequently applied to the land, and, as is well known in many parts of England, with injurious effects, if laid on in too large quantities. The cause of this hot or burning nature, as it is called, of magnesian lime, is not very satisfactorily ascertained. I shall, however, state two or three facts, which may assist in conducting us to the true cause.

1°. Quick-lime dissolves in 750 times its weight of water, at the ordinary temperature of the atmosphere, while pure magnesia requires 5142 times its weight. The magnesia, therefore, is not likely to injure living plants *directly* by entering into their roots in its *caustic* state, since lime which is seven times more soluble produces no injurious effect.

2°. It seems to be the result of experience, that magnesia in the state of carbonate is but slightly injurious to the land; some deny that in this state it has any injurious effect at all. This I fear is doubtful; we may infer, however, with some degree of probability, that it is from some property possessed by magnesia in the caustic state, and not possessed, or at least in an equal degree, either by *quick-lime* or by carbonate of magnesia, that its evil influence is *chiefly* to be ascribed.

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[*] Sprengel, *Chemie* I., p. 645.

3°. When exposed to the air, quick-lime speedily absorbs water and carbonic acid from the air, forming first a *hydrate*[*] in fine powder, and then a carbonate. Caustic magnesia absorbs both of these more slowly than lime does, and in the presence of the latter, or when mixed with it, must absorb them more slowly still, since the lime will seize on the greater portion of the moisture and carbonic acid which exists in the air, immediately surrounding both. When slaked in the air also, the lime may be transformed in great part into carbonate while the magnesia still remains in the state of hydrate, and it is a property of this hydrate to attract carbonic acid more feebly and slowly, even than the newly burned magnesia as it comes from the kiln. Hence when buried in the soil, after the lime has become nearly all transformed into carbonate, the magnesia may still be all either in the dry caustic state, or in that of a hydrate only.

4°. Now there exist in the soil, and probably are exuded from the living roots, various *acid* substances, both of organic and of inorganic origin, which it is one of the functions of lime, when applied to the land, to combine with and render innoxious. But these acid compounds unite rather with the caustic magnesia, than with the lime which is already in combination with carbonic acid—and form *salts*[†] which generally are *much more soluble in water* than the compounds of lime, with the same acids. Hence the water that goes to the roots, reaches them more or less loaded with magnesian salts, and carries into the vegetable circulation more magnesia than is consistent with the healthy growth of the plant.

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[*] Compounds of substances with water are called *hydrates* (from the Greek word for water.) Thus slaked lime, a compound of lime with water, is called *hydrate of lime*—and the native compound of magnesia with water, alluded to in the text, is called *hydrate of magnesia*.

[†] Compounds of the *bases*,—potash, soda, lime, magnesia, &c.,—with *acids*,—sulphuric, muriatic, nitric, acetic (or vinegar), &c.,—are called salts.

It is hazardous to reason from the phenomena of animal to those of vegetable physiology, yet if lime and magnesia have the power of differently affecting the animal economy, why may they not also very differently affect the vegetable economy? And since in the same circumstances, and in combination with the substances they meet with in the same soils, magnesia is capable of entering more largely into a plant by its roots—may not magnesia be considered capable of poisoning a plant, when lime in the same condition would only improve the soil?

I have said that it may be doubted whether magnesia in the state of carbonate is wholly unhurtful to the land. This doubt rests on the fact that the magnesia *retains* its carbonic acid more feebly than lime does—and therefore its carbonate is the more easily decomposed when an acid body comes in contact with both. Though, therefore, the magnesian carbonate will not lay hold of all acid matter so readily and surely as caustic magnesia may, still occasions may occur where acid matters being abundant in the soil, so much carbonate of magnesia may be decomposed and dissolved as to render the water absorbed by its roots destructive to the health or life of a plant.

In reference to this point, however, it must be distinctly understood, that magnesia is one of the kinds of inorganic food most necessary to plants, that a certain quantity of it in the soil is absolutely necessary to the growth of nearly all cultivated plants, and that it is only when it is conveyed to the roots in too large a quantity, that it proves injurious to vegetable life.

5°. *Magnesium* is the metallic basis of magnesia. Little is known of its properties, owing to the difficulty of preparing it in any considerable quantity for the purpose of experiment. It is a white metal, which, when heated in the air, takes fire and burns, combining with the oxygen of the atmosphere, and forming magnesia. It is not known to occur in nature in an elementary form, and therefore is not supposed directly to influence vegetation.

6°. *Chloride of Magnesium.*—When calcined or carbonated magnesia is dissolved in muriatic acid, and the solution evaporated to dryness, a white mass is obtained which is a *chloride of magnesium*, consisting of magnesium and chlorine only. This compound occurs not unfrequently in the soil, associated with chloride of calcium. It is met with also in the ash of plants, while in sea water, and in that of some salt lakes, it exists in very considerable quantity. Thus 100 parts of the water of the Atlantic have been found to contain 3¼ of chloride of magnesium, while that of the Dead Sea yields about 24 parts of this compound.* Hence it is present in great abundance in the mother liquor of the salt pans, and it is from the refuse chloride in this liquor that the magnesia of the shops, as above stated, is frequently prepared.

The chloride of magnesium has not hitherto been made the subject of direct experiment as a fertilizer of the land. From the fact, however, that plants require much magnesia and some chlorine, there is reason to believe that if cautiously applied, it might prove beneficial in some soils, and especially to grain crops. Its extreme solubility in water, however, suggests the use of caution in its application. The safest method is to dissolve it in a large quantity of water, and to apply it to the young plant by means of a water-cart. In this way the refuse of the salt works might, in some localities, be made available to useful purposes.

The chloride of magnesium is decomposed both by quicklime and by carbonate of lime; hence when applied to a soil containing lime in either of these states, chloride of calcium and caustic or carbonated magnesia will be produced.

7°. *Nitrate of Magnesia* is formed by dissolving carbonate of magnesia in nitric acid, and evaporating the solution. It attracts moisture from the air with great rapidity, and runs into a liquid. It is probably formed naturally in soils containing magnesia, in the same way as nitrate of lime is known to be produced in soils containing lime.† No direct experiments have yet been made as to its effects upon vegetation; but there can be no doubt that it would prove highly beneficial, could it be procured at a sufficiently cheap rate to admit of its economical application to the land.

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* 100 parts of the water of the Dead Sea contain also about 10½ of chloride of calcium, and nearly 8 of common salt.

† See Lecture VIII., p. 237.

8°. *Sulphate of Magnesia*—the common Epsom salts of the shops—is formed by dissolving carbonate of magnesia in diluted sulphuric acid. It exists in nearly all soils which are formed from, or are situated in, the neighbourhood of rocks containing magnesia. In some soils it is so abundant that in dry weather it forms a white efflorescence on the surface. This has been observed to take place in Bohemia, Hungary, and parts of Germany, and it may be frequently seen in warm summer weather in the neighbourhood of Durham.*

This salt has been found by Sprengel to act upon vegetation precisely in the same way as gypsum does, and on the same kind of plants. It must be used, however, in smaller quantity, owing to its great solubility. Its higher price will prevent its ever being *substituted* for gypsum, as a top-dressing for clover, &c., but it is worth the trial, whether corn plants, the grain of which contains much magnesia, might not be benefitted by the application of a small quantity of this sulphate—along with such other substances as are capable of yielding the remaining constituents which compose the inorganic matter of the grain. Its price is not too high to admit of this more restricted application.†

9°. *Phosphate of Magnesia.*—Magnesia exists in combination with phosphoric acid, in the solids and fluids of all animals, though not so abundantly as the phosphates of lime. In most soils phosphate of magnesia is probably present in minute quantity, since in the ashes of some varieties of grain it is found in very considerable proportion.

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* It occasionally collects beneath the plaster of old walls in Durham. In one of the lower rooms of the old Exchequer buildings, I found it forming an extensive layer nearly half an inch thick, beneath the damp plaster. The magnesia is derived from the magnesian limestone, used both for mortar and for a building stone.

† Its price in Newcastle in the state of crystals, is about 10s. a cwt. The impure salt collected at the alum works on the Yorkshire coast, might be obtained, I should suppose, for little more than half this price.

Its action upon vegetation has never been tried directly, but as it exists in urine, and in most animal manures—a portion of their efficacy may be due to its presence. In turf ashes, which often prove a valuable manure, it is sometimes met with in appreciable quantity, and their beneficial operation in such cases has been attributed in part to the agency of this phosphate.

IX.—ALUMINIUM, ALUMINA, SULPHATE AND PHOSPHATE OF ALUMINA—ALUM.

1°. *Aluminium* is another of those rare and little known metals, the existence of which was established by Sir H. Davy. In combination with oxygen it forms *alumina*, and in this state it exists in such abundance in nature, as to form a large portion of the entire crust of the globe.

2°. *Alumina, the earth of Alum.*—When common alum is dissolved in water, and a solution of carbonate of soda or of ammonia is added to it, a bulky white powder falls, which when collected on a filter, well washed and dried, is nearly pure alumina. This substance occurs on the surface of the earth in a pure state only in some rare minerals, such as the corundum, the sapphire, and the ruby,—but it constitutes a large proportion of all the slaty and shaley rocks. It is the principal ingredient also of all clays (pipe-clay for example) and clayey soils, which increase in tenacity in proportion to the quantity of alumina they contain.

When pure, it is a white tasteless earthy substance, which adheres to the tongue, has a density of 2·00, and is insoluble in water, but dissolves readily in caustic potash and soda and in most acids, at least when newly thrown down from a solution of alum. When heated to redness, however, it becomes hard and dense, as in burned clay and fire bricks, and can then only be dissolved with extreme difficulty, even by the strongest acids. Though it exists so largely in the soil, it contributes but little in a direct manner to the *nourishment* of plants. The ash they leave contains in general but a very small per-centage of alumina, as will more clearly appear hereafter,—the principal agency, therefore, of this ingredient of the soil is most probably of an indirect, perhaps of a mechanical kind.

It has been stated in a preceding Lecture (p. 23), that charcoal has the property of absorbing gaseous substances, such as ammonia, from the atmosphere, and that the action of charcoal powder, in promoting vegetation, has been in a great measure ascribed to this property. The same property, we have also seen (p. 202), is ascribed to gypsum, and hence its fertilizing action has been explained in a similar way. Alumina is said to be equally absorbent of ammonia ; and the use of burned clay as a top-dressing, so strongly recommended by General Beatson,* is ascribed to its power of abstracting ammonia from the air, and fixing it in the soil ready to be conveyed by the rains to the roots of the plants that grow upon it (Liebig, p. 90). It has been already shown (p.202, *note*), that this mode of accounting for the action of gypsum is not satisfactory as a *sole* cause—in the case of alumina, the fact of its absorbing ammonia is hypothetical,† and therefore the explanation founded upon this fact is not to be implicitly relied upon.

3°. ***Sulphate of Alumina.***—When alumina is digested in diluted sulphuric acid, it readily dissolves, and forms a solution of sulphate of alumina. This solution is characterized by a remarkable and almost peculiar sweetish astringent taste. When evaporated to dryness it yields a white salt, which dissolves in twice its weight of water only, and when exposed to the air, attracts moisture rapidly, and spontaneously runs to a liquid. This salt exists in some soils, especially in those of wet, marshy, and peaty lands.

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* *New System of Cultivation.* London, 1820.

† Because clays of many varieties—pipe-clay for example—contain traces of ammonia, which they evolve when moistened with a solution of caustic potash,—it is inferred that they have absorbed this ammonia from the atmosphere. The same inference is drawn from the fact of its presence in oxide of iron. Liebig's *Organic Chemistry applied to Agriculture*, p. 89.—In neither case does the inference appear to me to be *necessary*. Much of the ammonia may have been formed in the soil, during the oxidation of the iron itself, or during the decay of vegetable and animal substances.—See above, Lecture VIII., p. 236.

No experiments have yet been made with the view of determining its direct influence upon vegetation.

4°. *Phosphates of Alumina.*—In combination with phosphoric acid, alumina forms one compound well known to mineralogists, by the name of *wavellite.* This mineral, however, occurs in too small quantity, to be an object of interest to the agriculturist.

Phosphoric acid is disseminated in some form or other throughout our clayey soils, though in very small and variable quantity. It is most probable that in these soils a portion of the acid at least, is in combination with the alumina in the state of phosphate. One of the most difficult problems in analytical chemistry is to effect a perfect separation of a small proportion of phosphoric acid from alumina, and rigorously to estimate its quantity; hence in the greater part of the analyses of soils hitherto published, this most important ingredient in a fertile soil (the phosphoric acid), when in combination with, or in presence of alumina, has either been altogether neglected, or rudely guessed at, or indicated by a rough approximation only. We have no direct proof, therefore, of the extent to which the phosphates of alumina exist in different soils.

5°. *Alum.*—The common alum of the shops owes its well known sweetish astringent taste to the presence of the above sulphate of alumina. It consists in 100 parts of about 40 of sulphate of alumina, 14½ of sulphate of potash,* and 45½ of water. Alum is formed naturally on many parts of the earth's surface, especially as an efflorescence on certain soils, and on some rocks when exposed to the air,—as on the alum shales of the Yorkshire coast. It is largely manufactured by calcining, and afterwards washing these alum shales.

Alum has not been extensively tried as a manure. Its composition, however, would lead us to expect it to exert a beneficial influence on the growth of many plants—while the price, especially of the less pure varieties, is such as to admit of its being applied to the land at a comparatively small cost. From some experiments made on a small scale, Spren-

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† Described p. 277.

gel considers it highly worthy the attention of the practical agriculturist.

X.—SILICON, SILICA, SILICATES OF POTASH, OF SODA, OF LIME, OF MAGNESIA, AND OF ALUMINA.

1°. *Silica.*—The chief ingredient in all sand-stones and in nearly all sands and sandy soils, is known to chemists by the name of silica. Flints are nearly pure silex or silica—common quartz rock is another form of the same substance—while the colourless and more or less transparent varieties of rock crystal and chalcedony present it in a state of almost perfect purity. It exists abundantly in almost all soils, constituting what is called their *silicious* portion, and is found in the ashes of all plants without exception, but especially in those of the grasses. Silica is without colour, taste, or smell, and cannot be melted by the strongest heat. As it occurs in the mineral kingdom—in the state of flint, of quartz, or of sand—it is perfectly insoluble in pure water, either cold or hot, does not dissolve in acid and very slowly in alkaline solutions. When mixed with potash, soda, or lime, and heated in a crucible to a high temperature, it melts and forms a glass. *Window* and *plate* glass consists chiefly of silica, lime, and soda, *flint* glass contains litharge [oxide of lead] in place of the lime. But though the various forms of more or less pure silica, which are met with in the mineral kingdom, are absolutely insoluble in water, yet it sometimes occurs in nature, and can readily be prepared in a state in which pure water, and even acid solutions, will take it up in considerable quantity. In this state it may be obtained by reducing crown-glass to a fine powder, and digesting it in strong muriatic acid, or by melting quartz sand in a large quantity of potash or soda, and afterwards treating the glass that is formed with diluted muriatic acid.

Silica is one of the most abundant substances in nature, and in combination with potash, soda, lime, magnesia, and alamina, it forms a large portion of all the so-called crystalline (granitic, basaltic, &c.) rocks. The compounds of silica, with these bases, are called *silicates.* By the action of the air, and other causes, these silicates undergo decomposition, as glass does when digested with muriatic acid, and the silica is separated in the *soluble* state. Hence its presence in considerable quantity in the waters of many mineral and especially hot mineral springs, and in appreciable proportion in nearly all waters that rise from any considerable depth beneath the surface, or have made their way through any considerable extent of soil.

In the substance of living vegetables it exists, for the most part, in this state of combination—as well as in the form of an extremely delicate tissue, of which the fibres are exceedingly minute, and therefore expose a large surface to the action of any decomposing agent, or of any liquid capable of dissolving it. In the compost heaps these silicates undergo decomposition,—and the more readily the less they have been previously dried, or the greener they are,—and the silica of the plant is liberated in a soluble state. Whether or not, when thus liberated, it will be carried, *uncombined*, into the roots of the plants by the water they absorb, will depend upon the quantity of potash or soda in the compost or in the soil, and upon other circumstances hereafter to be explained.

2°. *Silicon* is known only in the state of a dark brown powder, which has not as yet been met with in nature in an elementary form, and is prepared by the chemist with considerable difficulty. When heated in the air, or in oxygen gas, it burns, combines with oxygen, and is converted into *silica*. Silica, therefore, in its various forms, is a compound of silicon with oxygen. It consists of 48 per cent. of the former and 52 per cent. of the latter.

3°. *Silicates of Potash and Soda.*—When finely powdered quartz, flint, or sand is mixed with from one-half to three times its weight of dry carbonate of potash or soda, and exposed to a strong heat in a crucible, it readily unites with the potash or soda, and forms a glass. This glass is a *silicate* or a mixture of two or more *silicates* of potash or soda. Silica combines with these *alkalies*[*] in various proportions. If it be melted with much potash, the glass obtained will be readily soluble in water; if with little, the silicate which is formed will resist the action of water for any length of time. Window and plate-glass contain much silicate of potash or soda. A large quantity of alkali renders these varieties of glass more fusible and more easily worked, but at the same time makes them more susceptible of corrosion or tarnish by the action of the air.

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[*] Potash, soda, and ammonia are called *alkalies;* lime and magnesia are *alkaline earths.* See Lecture III., p. 67, *note.*

The insoluble silicates of potash and soda exist also in many mineral substances. In the felspar and mica, of which granite in a great measure consists, they are present in considerable quantity. The former (felspar) contains one-third of its weight of an insoluble silicate of potash, consisting of nearly equal weights of potash and silica. In the variety called *albite* or *cleavelandite*, silicate of soda alone is found, while in some other varieties a mixture of both silicates is present. In mica from 12 to 20 per cent. of the same silicate of potash occurs, but soda can rarely be detected in this mineral. The trap-rocks also (whin, basalt, green-stone), so abundant in many parts of our island, consist almost entirely of *silicates*. Among these, however, the silicates of potash and soda rarely exceed 5 or 6 per cent. of the whole weight of the rock, and are often entirely absent.

These insoluble silicates also exist in the stem and leaves of nearly all plants. They are abundant in the stems of the grasses, especially in the straw of the cultivated grains, and form a large proportion of the ash which is left when these stems are burned (p. 261.)

It is important to the agriculturist to understand the relation which the carbonic acid of the atmosphere bears to these alkaline silicates which occur in the mineral and vegetable kingdom. Insoluble as they are in water, they are slowly decomposed by the united action of the moisture and carbonic acid of the air, the latter taking the potash or soda from the silica, and forming *carbonates* of these bases. In consequence of this decomposition the rock disintegrates and crumbles down, while the soluble carbonate is washed down by the rains or mists, and is borne to the lower grounds to enrich the alluvial and other soils, or is carried by the rivers to the sea.

In some cases, as in the softer felspar of some of the Cornish granites, this decomposition is comparatively rapid, in others, as in the Dartmoor and many of the Scottish granites, it is exceedingly slow,—but in all cases the rock crumbles to powder long before the whole of the silicates are decomposed, so that potash and soda are always present in greater or less quantity in granitic soils, and will continue to be separated from the decaying fragments of rock for an indefinite period of time.

But the silica of the felspar, or mica, or zeólitic* trap, when thus deprived of the potash with which it was combined, is in that peculiar state, in which, as above described [p. 303], it is capable of being dissolved in small quantity by pure water, and more largely by a solution of carbonate of potash or soda. Hence the same rains or mists which dissolve the alkaline carbonates so slowly formed, take up also a portion of the silica, and convey it in a state of solution to the soils or to the rivers. Thus, with the exception of the dews and rains which fall directly from the heavens, few of the supplies of water by which plants are refreshed and fed, ever reach their roots entirely free from silica, in a form in which it can readily enter into their roots, and be appropriated to their nourishment.

In the farm-yard and the compost-heap, where vegetable matters are undergoing decomposition, the silicates they contain undergo similar decompositions, and, by similar chemical changes their silica is rendered soluble, and thus fitted, when mixed with the soil, again to minister to the wants and to aid the growth of new races of living vegetables.

4°. *Silicates of Lime.*—A mixture of sand or flint with quick-lime readily melts and forms a glassy silicate or a mixture of two or more silicates of lime. These silicates are also present in large quantity in window and plate-glass, and in some of the crystalline† (granite and trap) rocks. In felspar and mica, which abound, as we have seen, in the alkaline silicates, it is rare that any lime can be detected. In that variety of granite, however, to which the name of syenite is given by mineralogists, *hornblende* takes the place of *mica*, and some varieties of this hornblende contain from 20 to 35 per cent. of silicate of lime. This silicate (containing 38 per cent. of lime) is almost always present in the basaltic and trap-rocks, and sometimes, as in the augitic* traps, in a proportion much larger than that in which it exists in the unmixed hornblende. To this fact we shall have occasion to revert when we come to consider the relative fertility of different soils and the causes on which the difference of their several productive powers most probably depends.

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* The trap-rocks always more or less abound in *zeolitic* minerals, of which there is a great variety, and in which nearly all the alkali present in these (trap) rocks is contained.

† So called because the minerals of which they consist are generally in a *crystallized* state.

Silicates of lime are also found in the ash, and probably† exist in the living stem and leaves of plants.

Like the similar compounds of potash and soda, the silicates of lime are slowly decomposed by the united agency of the moisture and the carbonic acid of the atmosphere. Carbonate of lime is formed, and silica is set at liberty. This carbonate of lime dissolves in the rains or dews which descend loaded with carbonic acid,‡ and the same waters take up also a portion of the soluble silica and diffuse both substances uniformly through the soil in which the decomposition takes place, or bear them from the higher grounds to the rivers and plains. The sparing but constant and long-continued supply of lime thus afforded to soils which rest upon decayed trap, or which are wholly made up of *rotten* rock, has a material influence upon their well-known agricultural capabilities.

5°. *Silicates of Magnesia.*—In combination with magnesia in different proportions, silica forms nearly the entire mass of those common minerals known by the names of serpentine and talc. In hornblende also and augite, silicates of magnesia exist in considerable quantity. They must, therefore, be present in greater or less quantity in soils which are *directly* formed from the decomposition of such rocks. Like the silicates of lime, however—though more slowly than these—they will undergo gradual decomposition by the action of the carbonic acid of the atmosphere, and of the acids produced in the soil by vegetation and by the decay of organic matter. The magnesia, like the lime, will thus be gradually brought down, in a state of solution (p. 295), from the higher grounds, or washed out of the soil, till at length it may wholly disappear from any given spot.*

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* Rocks of which the mineral called *augite* forms a more or less considerable part.

† I say *probably*, because if uncombined silica be present in hay or straw along with carbonate or oxalate of lime, the heat employed in completely burning away the organic matter may be sufficient to cause the lime and silica to unite and form a silicate which will afterwards be found in the ash, though none previously existed in the stem.

‡ See page 59.

6°. *Silicates of Alumina.*—Silica combines with alumina also in various proportions, forming silicates, which exist abundantly in nature in the crystalline rocks, and may also, like the other silicates, be formed by art. Felspar, mica, hornblende, and the augites, which abound in the trap-rocks, all contain much alumina in combination with silica, and we shall probably not be very far from the truth in assuming that upwards of one-half by weight of the trap-rocks in general—as well as of the hornblendes, micas, and felspars, of which so large a part of the granitic rocks is composed—consists of silicates of alumina. The alumina itself in these several minerals varies from 11 to 38 per cent., but generally averages about 20 per cent. of their entire weight.

These silicates, when they occur alone, unmixed or uncombined with other silicates, decompose very slowly by the action of the atmosphere. They disintegrate, however, and fall to powder, when the alkaline silicates with which they are associated in felspar, &c., are decomposed and removed by atmospheric causes. In this way the deposits of porcelain clay, so common in Cornwall and in other countries, have been produced from the disintegration of the felspathic rocks, and the clayey soils which occur in granite districts have not unfrequently had a similar origin.

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* I am indebted to Sir Charles Lemon for the analysis of a soil, on part of his own property, resting on serpentine, and bearing only *Erica vagans*, which illustrates the statement in the text. This soil consists of silica 70, alumina with a trace of gypsum 20, oxide of iron 6·2, and vegetable matter 3·8 per cent. If this soil has been formed from the rock on which it rests, the magnesia has been wholly washed out. Its constitution, however, points rather to a decayed felspar or slate rock, as the source from which it has been derived.

When contained in the soil, the silicates of alumina undergo a slow decomposition from the action of the various acid substances to which they are exposed. A portion of their alumina is dissolved and separated by these acids, and in this soluble state is either conveyed to the roots of plants or is washed from the soil by the rains—or by the waters that arise from beneath.

The ash of plants contains only a very small proportion of alumina, yet even this small quantity they cannot derive from the silicates of this substance, since these are all insoluble in water—as alumina itself is. They obtain it, therefore, from some of those soluble compounds of alumina of which I have spoken as being either occasionally present (p. 301), or as being naturally formed in the soil.

General remarks on these Silicates.—Of all these silicates it may be remarked in general—

1°. That besides existing in the minerals above-mentioned, and from which they are conveyed into the soil, they *are also slowly formed in the soil itself*, when the ingredients of which they severally consist are naturally present in, or are artificially added to, the soil. Hence, the addition of potash or soda to the land may cause the production of silicates of these alkalies—probably soluble silicates—which water will be capable of dissolving and bearing to the extremities of the roots. Hence also, in a sandy soil, the addition of lime may give rise to the production of insoluble silicates of this earth,—and the beneficial effect of the lime upon the land may thus sooner cease to be observable than in soils of a different character, where it is not so liable to be locked up in an insoluble state of combination; and

2°. That with the exception of those of potash and soda, which contain much alkali, these silicates are all insoluble in water, and thus not directly available to the nutrition of plants. Except those of alumina, however, they are all slowly decomposed by atmospheric agents, and their constituent elements thus brought, to a certain extent, within the reach of plants; while, without exception, they are all capable of decomposition in the soil by the agency of the acid substances, chiefly organic, which there exist, or which are produced during the growth and decay of vegetable substances. From this latter source, the chief supply of the ingredients contained in the silicates, is, in most soils, derived by living plants.

To this cause is attributed the surprising effect often observed to follow from the addition of vegetable matter to a sandy soil on which a previous addition of lime had ceased to produce any further beneficial effect. The organic acids formed by the vegetable matter during its decay decompose the silicates of lime previously produced, and thus liberate the lime from its insoluble state of combination. But when the silicates have been all decomposed by this agency, the further addition of vegetable matter ceases necessarily to produce the same remarkable effects.

XI.—THE OXIDES, SULPHURETS, SULPHATES AND CARBONATES OF IRON.

1°. *Oxides of Iron.*—It is well known that when metallic iron is exposed to moist air, it gradually rusts and becomes covered with, or wholly changed into, a crumbling ochrey mass of a reddish brown colour. This powder is a compound of iron and oxygen only, containing 69⅓ per cent. of the former, and 30⅔ per cent. of the latter.

When iron is heated in the smith's forge, and then beat on the anvil, a scale flies off which is of a black colour, and when crushed gives a black powder. This also consists of iron and oxygen only, but the proportion of oxygen is not so great as in the red powder above described. In both cases the iron has derived its oxygen from the atmosphere.

To these compounds of iron, with oxygen, the name of *oxides* is given. There are only two which are of interest to the agriculturist, namely,—

	CONSISTING OF			
	Iron.	Oxygen.	Symbol.	Colour.
The *first* oxide, .	69·34	30·66	Fe_2O_3	Red.
The *second* oxide[*]	77·23	22 77	$Fe\ O$[†]	Black.

Both of these exist abundantly in nature, and are present to a greater or less extent in all soils. The second or *per*-oxide, however, is by far the most abundant on the earth's surface, and the reddish colour observable in so many soils is principally due to the presence of this oxide.

The first oxide rarely occurs in the soil except in a state of combination with some acid substance,—and so strong is its tendency to combine with more oxygen, that when exposed to the air, even in a state of combination, it rapidly absorbs this element from the atmosphere and changes into per-oxide. This change is observable in all chalybeate springs, in which, as they rise to the surface, the iron is generally held in solution in the state of the first oxide. After a brief exposure to the air, more oxygen is absorbed, and a reddish pellicle is formed on the surface, which gradually falls and coats the channel along which the water runs, with a reddish sediment of insoluble per-oxide.

Both oxides are insoluble in pure water, and both dissolve in water containing acids in solution. The first oxide, however, dissolves in much greater quantity in the same weight of acid, and it is the compounds of this oxide which are usually present in the soil, and which, in boggy lands, prove so injurious to vegetation.[‡]

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[*] The *first* is also called the *prot*-oxide, the *second* either the *sesqui*, or *more usually* the *per*-oxide of iron.

[†] Iron is represented by the symbol Fe, the initial letters of its Latin name (ferrum).

[‡] "That layer of soil (says Sprengel), is always especially rich in iron, over which the heel of the plough glides in preparing the land. The friction of the soil continually rubs off particles of iron, which absorb oxygen and change into the *first* oxide. Hence this part of the soil is always darker in colour than the rest; hence also the reason why the soil, after deep ploughing, remains unproductive sometimes for several years."—*Chemie* I., p. 428. While we admit that the presence of the first oxide of iron in the subsoil affects its fertility, when brought to the surface, we may doubt whether *much* of that iron can have been derived from the tear and wear of the plough.

The second oxide possesses two properties which, in connection with practical agriculture, are not void of some degree of importance.

1°. In a soil which contains much vegetable matter in a state of decay, the per-oxide is frequently deprived of one-third of its oxygen by the carbonaceous matter,* and is thus converted into the first oxide which readily dissolves in any of the acid substances with which it may be in contact. In this state of combination it is more or less soluble in water, and in some localities may be brought to the roots of plants in such quantity as to prove injurious to their growth.

2°. The red oxide of iron is said, like alumina (p. 301), to have the property of absorbing ammonia, and probably other gaseous substances and vapours, from the atmosphere and from the soil. In that which occurs in nature, either in the soil or near the surface of mineral veins, traces of ammonia can generally be detected. Since then ammonia is so beneficial—according to some so indispensably necessary—to vegetation, the property which the per-oxide of iron possesses of retaining this ammonia when it would otherwise escape from the soil, or of absorbing it from the atmosphere, and thus bringing it within the reach of plants, must also be indirectly favourable to vegetation—where the soil contains it in any considerable quantity.

An important practical precept is also to be drawn from these two properties of this oxide. A red irony soil, to which manure is added, should be frequently turned over, and should be kept loose and pervious to the air, in order that the formation of prot-oxide (first oxide) may be prevented as much as possible; and it may occasionally be summer-fallowed with advantage, in order also that the per-oxide may absorb from the air those volatile substances which are likely to prove beneficial to the growth of the future crops.

2°. *Sulphurets of Iron.*—Iron occurs in nature combined with sulphur in two proportions, forming a sulphuret and a *bi*-sulphuret. These consist respectively—

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* The carbon of the vegetable matter combines with the oxygen of the oxide to form *carbonic acid*. See p. 86.

	Iron.	Sulphur.	Symbol.
The sulphuret	62·77	37·23	Fe S
The bi-sulphuret of .	45·74	54·26	Fe S_2

and are both tasteless and insoluble in water.

1°. The first of these, the sulphuret (Fe S), occurs occasionally in boggy and marshy soils, in which salts of iron exist, or into which they are carried by rains or springs. It is not itself directly injurious to vegetation, but when exposed to the air it absorbs oxygen and forms *sulphate* of iron, which, when present in sufficient quantity, is eminently so.*

2°. The *bi-sulphuret*, or common iron pyrites (Fe S_2), is exceedingly abundant in nature. It occurs in nearly all rocky formations—and in most soils. It abounds in coal, and is the source of the sulphurous smell which many varieties emit while burning. It generally presents itself in masses of a yellow colour and metallic lustre, more or less perfectly crystallized in cubical forms, so brittle and hard as to strike fire with steel, and of a specific gravity four and a half times greater than that of water (Sp. gr. 4, 5). When heated in close vessels it parts with nearly one-half of its sulphur, and hence is often distilled for the sulphur it yields.

In the air it absorbs oxygen, in some cases—as in the waste coal-heaps—with such rapidity as to heat, take fire, and burn. By this absorption of oxygen (oxidation), sulphuric acid and sulphate of iron are produced. In the alum shales the iron pyrites abounds, and these are often burned for the purpose of converting the sulphur and sulphuric acid for the subsequent manufacture of alum.

3°. *Sulphates of Iron.*—Of the sulphates of iron which are known, there is only one—the common *green vitriol* of the shops—that occurs in the soil in any considerable quantity. There are few soils, perhaps, in which its presence may not be detected, though it is in bogs and marshy places that it is most generally and most abundantly met with. It is often exceedingly injurious to vegetation in such localities, but it is decomposed by quick-lime, by chalk, and by all varieties of marl, and thus its noxious effects may in general be entirely prevented. To soils which abound in lime, it may even be applied with a beneficial effect.

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* Yet in small quantity it may be beneficial. Thus Sprengel mentions that the subsoil of a moor near Hanover, which contains some of this sulphuret of iron, produces astonishing effects when laid as a top-dressing on the grass lands. The explanation of this is, that the pyrites absorb oxygen and is converted into sulphate, and thus reproduces the remarkable effects observed on the addition of gypsum, of sulphuric acid, or of sulphate of soda to similar grass lands.

When a solution of this salt is exposed to the air it speedily becomes covered with a pellicle of a yellow ochrey colour, which afterwards falls as a yellow sediment. This sediment consists of *per*-oxide of iron, containing a little sulphuric acid; but by the separation of this oxide the sulphuric acid is left in excess in the solution, which becomes sour, and still more injurious to vegetation than before. In boggy places the waters impregnated with iron are generally more or less in this acid state, and lime, chalk, and marl, with perfect drainage, are the only available means by which such lands can be sweetened and rendered fertile.

When iron pyrites is exposed to the air it slowly absorbs oxygen, and is converted into *sulphate* of iron and sulphuric acid; on the other hand, the sour solution above mentioned, when placed in contact with vegetable matter, where the air is excluded, parts with its oxygen to the decaying carbonaceous matter, and is again converted into iron pyrites. These two opposite processes are both continually in progress in nature, and often in the same locality,—the one on the surface, where air is present; the other in the subsoil, where the air is excluded.

4°. *Carbonates of Iron.*—When a solution of the sulphate of iron, above described, is mixed with one of carbonate of soda, a yellow powder falls, which is *carbonate of iron*. This carbonate is found abundantly in nature. It is the state in which the iron exists in the ore (clay-iron ore), from which this metal is so largely extracted in our iron furnaces, and in the similar ore often found in the subsoil of boggy places, which is distinguished by the name of bog-iron ore.

Like the carbonate of lime, it is insoluble in water, but dissolves with considerable readiness in water charged with carbonic acid. In this state of solution it issues from the earth in most of our chalybeate springs, and it is owing to the escape of the excess of carbonic acid from the water, when it reaches the open air, that the yellow deposit of carbonate of iron more or less speedily falls.

The carbonate of iron, being insoluble in water, cannot be directly injurious to vegetation. When exposed to the air it gradually parts with its carbonic acid, and is converted into per-oxide of iron.

The ash of nearly all plants contains a more or less appreciable quantity of oxide of iron. This may have entered into the roots either in the state of soluble sulphate or of carbonate dissolved in carbonic acid, or of some other of those numerous soluble compounds of iron with *organic* acids, which may be expected to be occasionally present in the soil.

XII.—MANGANESE : OXIDES, CHLORIDES, CARBONATES, AND SULPHATES OF MANGANESE.

1°. *Manganese* is a metal which, in nature, is very frequently associated with iron in its various ores. It also resembles this metal in many of its properties. In the metallic state, however, it is not an object of manufacture, nor is it used for any purpose in the arts.

2°. *Oxides of Manganese.*—Manganese combines with oxygen in several proportions. The first oxide is of a light green colour, the second and third are black. The first is not known to occur in nature in an uncombined state, the two others exist abundantly in the common ores of manganese, and are extensively diffused, though in small quantity, through nearly all soils. They are all insoluble in water, but the two former dissolve in acids and form *salts*. Traces of these two oxides are also to be detected in the ash of nearly all plants.

3°. *Chloride, Carbonate, and Sulphate of Manganese.*—If any of these oxides be dissolved in muriatic acid a solution of *chloride* of manganese will be obtained.

If this solution of chloride of manganese be mixed with one of carbonate of soda, a white insoluble powder will fall, which is *carbonate* of manganese.

If this carbonate be dissolved in diluted sulphuric acid, or if any of the oxides be digested in this acid, a solution of *sulphate* of manganese will be formed.

The carbonate of manganese, and its oxides, will also dissolve, though more slowly, in acetic acid (vinegar), and in other organic acids which may be present in the soil, and will form with them other soluble salts.

The compounds of manganese exist in plants in much less quantity than those of iron ; but as its oxides, like those of iron, are insoluble in pure water, this metal most likely finds its way into the roots of plants in the state of one or other of the soluble compounds above described.

§ 2. *Tabular view of the constitution of the compounds of the inorganic elements above described.*

Having in the preceding section briefly described the several compounds of the *inorganic elements of plants*, which either enter into the constitution of vegetable substances, or are supposed to minister to their growth—it may prove useful hereafter, if I exhibit at one view the composition per cent. of the various oxides, chlorides, sulphurets, and oxygen-acid salts,* to which I have had occasion to direct your attention.

1°.—*Oxygen per cent. in the oxides of the inorganic elements.*

	Oxygen per cent.		Oxygen per cent.
Sulphurous Acid .	49·85	Alumina	46·70
Sulphuric Acid . .	59·86	Silica	51·96
Phosphoric Acid .	56·04	Prot-oxide of Iron . . .	22·77
Potash	16·95	Per-oxide of Iron	30·66
Soda	25·58	Prot-oxide of Manganese	22·43
Lime	28·09	Sesqui-oxide do. . . .	30·25
Magnesia	38·71	Per-oxide do. . . .	36·64

2°.—*Chlorine or Sulphur per cent. in the chlorides and sulphurets.*

	Chlorine per cent.		Sulphur per cent.
Chloride of Potassium	47·47	Sulphuret of Potassium	29·11
——— Sodium .	60·34	——— Sodium . .	40·88
——— Calcium .	63·36	——— Calcium .	44·00
——— Magnesium	73·65	——— Iron	37·23
First Chloride of Iron	56·62	Bi-Sulphuret of Iron, (Iron Pyrites)	47·08
Second do. do.	66·19		

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* So called because the acid they contain has *oxygen* for one of its constituents.

3°.—*Composition per cent. of the Saline combinations above described.*

	Acid.	Base.	Water.
Carbonate of Potash	31·91	68·09	
Bi-carbonate of do.	48·38	51·62	
Sulphate of do.	45·93	54·07	
Nitrate of do.	53·44	46·56	
Binoxalate of do. (Salt of sorrel) . .	52·64	34·29	13·07
Bitartrate of do. (Cream of tartar) .	70·28	24·96	4·76
Phosphate of do.	43·06	56·94	
Bi-phosphate of do.	60·20	39·80	
Carbonate of Soda (dry)	41·42	58·58	
———— (crystallized) . .	15·43	21·81	62·76
Bi-carbonate of Soda	58·58	41·42	
Nitrate of do.	63·40	36·60	
Sulphate of do. (dry) . . .	56·18	43·82	
———— do. (crystallized) . .	24·85	19·38	55·77
Phosphate of do.	53·30	46·70	
Bi-phosphate of do.	69·54	30·46	
Carbonate of Lime	43·71	56·29	
Sulphate of do. (Gypsum)	46·31	32·90	20·79
———— (burned)	58·47	41·53	
Nitrate of Lime	65·54	34·46	
Phosphate of Lime (Apatite)	45·52	54·48	
Bi-phosphate of Lime	71·48	28·52	
Earth of Bones	48·45	51·55	
Carbonate of Magnesia	51·69	48·31	
Bi-carbonate of do.	68·15	31·85	
Sulphate of do. (Epsom salts) . .	32·40	16·70	50·90
Nitrate of do.	72·38	27·62	
Phosphate of do.	63·33	36·67	
Sulphate of Alumina	70·07	29·93	
Phosphate of do.	67·57	32·43	
Silicate of Potash (soluble)	49·46	50·54	
Bi-silicate of do. (do.)	66·19	33·81	
Silicate of Soda (do.)	59·63	40·37	
Bi-silicate of do. (do.)	74·71	25·29	
Silicate of Lime.	61·85	38·15	
———— Magnesia	69·08	30·92	
———— Alumina	72·95	27·05	
Carbonate of Iron	38·63	61·37	
Sulphate of do. (crystallized) . . .	31·03	27·19	41·78
Carbonate of Manganese	38·27	61·73	
Sulphate of do. (crystallized) .	33·20	29·54	37·26

We shall have occasion to refer to the numbers in the above tables in our subsequent calculations.

§ 3. *On the relative proportions of the different inorganic compounds present in the ash of plants.*

Having thus made you acquainted with the general properties and composition of the several compound substances of which the ash of plants consists, we now advance to the consideration of the *relative proportions* in which these substances exist in the ash of the different kinds of plants usually cultivated for food.

We have seen (p. 261) that different species of plants leave very different quantities of ash when burned;—the ash left by different species contains also the above earthy and saline substances in very unlike proportions. This fact has already been stated generally (p. 264); we are now to illustrate it more fully, and to show the important practical deductions to which it leads.

I.—OF THE ASH OF WHEAT.

According to the analysis of Sprengel, 1000 lbs. of wheat leave 11·77 lbs., and of wheat straw 35·18 lbs. of ash, consisting of—

	Grain of Wheat.	Straw of Wheat.
Potash	2·25 lbs.	0·20 lbs.
Soda	2·40	0·29
Lime	0·96	2·40
Magnesia	0·90	0·32
Alumina, with a trace of Iron	0·26	0·90
Silica	4·00	28·70
Sulphuric Acid . . .	0·50	0·37
Phosphoric Acid . .	0·40	1·70
Chlorine	0·10	0·30
	11·77 lbs.	35·18 lbs.

If the produce of a field be at the rate per acre of 25 bushels of wheat, each 60 lbs., and if the straw* be equal to twice the weight of the grain, the quantity of each reaped per acre will be

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* The proportion of the straw to the seed in grain of all kinds is very variable. In wheat it is said to average twice the weight of the grain, but it is very often, even in heavy crops, 3 to 3½ times that weight.

Grain,.....1500 lbs. } from a produce of 25 bushels;
Straw,.....3000 lbs. }

so that the quantity of the different inorganic compounds carried off *from the soil of each acre* will be, in the grain ½ more than is represented in the second column, and in the straw 3 times as much as is represented in the third column.

II.—OF THE ASH OF BARLEY.

A thousand pounds of the grain of barley (two-rowed, *hordeum distichon*,) leave 23½ lbs., and of the ripe dry straw 52·42 lbs. of ash. This ash consists of—

	Grain.	Straw.
Potash	2·78 lbs.	1·80 lbs.
Soda	2·90	0·48
Lime	1·06	5·54
Magnesia	1·80	0·76
Alumina	0·25	1·46
Oxide of Iron . .	a trace.	0·14
Oxide of Manganese .	—	0·20
Silica	11·82	38·56
Sulphuric Acid . .	0·59	1·18
Phosphoric Acid .	2·10	1·60
Chlorine	0·19	0·70
	23·49 lbs.	52·42 lbs.

If the produce of a crop of barley amount to 38 bushels of 63 lbs. each per acre, and the straw exceed the grain in weight one-sixth, the weight of each reaped per acre will be about

2000 lbs. of grain, } from a produce of 38 bushels;
2300 lbs. of straw, }

and the inorganic matters carried off from the soil by each will be obtained by multiplying those contained in the second column (above) by 2, and in the third by 2⅓.

III.—OF THE ASH OF OATS.

In 1000 lbs. of the grain of the oat are contained about 26 lbs., and of the dry straw about 57½ lbs. of inorganic matter, consisting of—

	Grain.	Straw.
Potash	1·50 lbs.	8·70 lbs.
Soda	1·32	0·02
Lime	0·86	1·52
Magnesia	0·67	0·22
Alumina	0·14	0 06
Oxide of Iron	0·40	0·02
Oxide of Manganese	0·00	0·02
Silica	19·76	45·88
Sulphuric Acid	0·35	0·79
Phosphoric Acid	0·70	0·12
Chlorine	0·10	0·05
	25·80 lbs.	57·40 lbs.

If an acre of land yield 50 bushels, each 54 lbs., of oats, and ⅔ds* more in weight of straw, there will be reaped per acre,

Of grain 2250 lbs., } from a produce of 50 bushels;
Of straw 3750 lbs., }

and the weight of the inorganic matters carried off will be equal to 2¼ times the quantities contained in the second column, and 3¾ times those contained in the third column.

IV.—OF THE ASH OF RYE.

The weight of ash contained in 1000 lbs. of the grain of rye is 10½ lbs., and of the straw 28 lbs. This ash consists of

	Grain.	Straw.
Potash	5·32 lbs.	0·32 lbs.
Soda		0·11
Lime	1·22	1·78
Magnesia	0·44	0·12
Alumina	0·24	0·25
Oxide of Iron	0·42	
Oxide of Manganese	0·34	—
Silica	1·64	22·97
Sulphuric Acid	0·23	1 70
Phosphoric Acid	0·46	0·51
Chlorine	0·09	0 17
	10·40 lbs.	27·93 lbs.

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* Of all kinds of grain, the oat gives the most variable proportion of straw, that which is obtained at one time, and in one locality, being 2 or 3 times greater than that reaped in another.

Rye is remarkable for the quantity of straw it yields, which is often from 3 to 4 times the weight of the grain. The return in grain reaches about the same average as that of wheat. From an acre of land yielding a crop of 25 bushels, each 54 lbs., there would be reaped

Of grain 1350 lbs.; of straw 4000 lbs.;

the whole weight of inorganic matters contained in which is equal to ⅓ more than is represented in the second column, added to 4 times the weights contained in the third column.

V.—OF THE ASH OF BEANS, PEAS, AND VETCHES.

The ash of the seed and straw of the field bean, the field pea, and the common vetch (*vicia sativa*,) dried in the air—contains in 1000 lbs. the several inorganic compounds in the following proportions:—

	FIELD BEAN.		FIELD PEA.		COMMON VETCH.	
	Seed.	Straw.	Seed.	Straw.	Seed.	Straw.
Potash . .	4·15	16·56	8·10	2·35	8·97	18·10
Soda . .	8·16	0·50	7·39	—	6·22	0·52
Lime . .	1·65	6·24	0·58	27·30	1·60	19·55
Magnesia . .	1·58	2·09	1·36	3·42	1·42	3·24
Alumina . .	0·34	0·10	0·20	0·60	0·22	0·15
Oxide of Iron .	—	0·07	0·10	0·20	0·09	0·09
Do. of Manganese	—	0·05	—	0·07	0·05	0·08
Silica . .	1·26	2·20	4·10	9·96	2·00	4·42
Sulphuric Acid .	0·89	0·34	0·53	3·37	0·50	1·22
Phosphoric Acid	2·92	2·26	1·90	2·40	1·40	2·80
Chlorine . .	0·41	0·80	0·38	0.04	0·43	0·84
	21·36	31·21	24·64	49·71	22·90	51·01

On comparing the numbers in these columns, we cannot fail to remark,—

1°. How much potash there is in the straw of the bean and the vetch.

2°. That while there is only a trace of soda in any of the three straws, there is a considerable quantity in all the seeds.

3°. How large a proportion of lime exists in the *straw* of the pea and of the vetch—compared with that of the bean—and how much larger the proportion is in all the straws than in any of the grains—and

4°. That the quantity of silica in pea straw is double of what is contained in the straw of the vetch, and 4 times that of the bean straw.

The produce of straw from these three varieties of pulse is very bulky, but varies in weight from 1 to 1¼ tons—or is on an average about 2300 lbs. per acre. The produce of grain is still more variable.

The bean gives from 16 to 40 bushels, of about 63 lbs.
The pea .... 12 to 84 ...... of .... 64 lbs.
The vetch .... 16 to 40 ...... of .... 66 lbs.

The mean return from beans is estimated by Schwertz* at 25 bushels (1600 lbs.), from peas at 15 bushels (1000 lbs.), and from vetches at 17 bushels (1100 lbs.) per acre.

The quantity of the several inorganic matters, therefore, carried off from an acre in the straw of these crops, will be about 2½ times the weights given in the table—and in the grains—where the crop is near the above average—1¼ times the weights in the tables for beans and for peas, and for vetches very nearly the actual weights above given.

VI.—THE ASH OF THE TURNIP, CARROT, PARSNIP, AND POTATOE.

These four roots, as they are carried from the field, contain respectively in ten thousand pounds—

	TURNIPS.		Carrot.	Parsnip.	POTATOES.	
	Roots.	Leaves.			Roots.	Tops.
Potash . .	23·86	32·3	35·33	20·79	40·28	81·9
Soda . .	10·48	22·2	9·22	7·02	23·34	0·9
Lime . .	7·52	62·0	6·57	4·68	3·31	129·7
Magnesia .	2·54	5·9	3·84	2·70	3·24	17·0
Alumina . .	0·36	0·3	0·39	0·24	0·50	0·4
Oxide of Iron .	0·32	1·7	0·33	0·05	0·32	0·2
Ox. of Manganese	—	—	0·60	—	—	—
Silica . .	3·88	12·8	1·37	1·62	0·84	49·4
Sulphuric Acid	8·01	25·2	2·70	1·92	5·40	4·2
Phosphoric Acid	3·67	9·8	5·14	1·00	4·01	19·7
Chlorine . .	2·39	8·7	0·70	1·78	1·60	5·0
	63·03	180·9	66·19	41·80	82·83	308·4

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* *Anleitung Zum Praktischen Ackerbau* II., p. 346.

These roots, as already stated (note p. 261), contain very much water, so that in a dry state, the *proportion* of inorganic matter present in them, is very much greater than is represented by the above numbers. I have, however, given the quantities contained in the crop as it is carried from the field, as alone likely to be of practical utility.

The crops of these several roots vary very much in different localities, being in some places twice and even thrice as much as in others—every nine tons, however, which are carried off the ground, contain about twice the weight of saline and earthy matters, indicated by the numbers in the table.

VII.—OF THE ASH OF THE GRASSES AND CLOVERS.

The following table might have been much enlarged. I have thought it necessary, however, to introduce in this place only, those species of grass and clover which are in most extensive use. I have also calculated the weights given below, for these plants in the *state of hay only*, as the succulency of the grasses,—that is, the quantity of water contained in the green crop,—varies so much that no correct estimate could be made of the quantity of inorganic matter present in hay or grass, from a knowledge of its weight in the green state only :

	Rye Grass Hay.	Red Clover.	White Clover.	Lucerne.	Saintfoin.
Potash . . .	8·81	19·95	31·05	13·40	20·57
Soda . . .	3·94	5·29	5·79	6·15	4·37
Lime . . .	7·34	27·80	23·48	48·31	21·95
Magnesia . .	0·90	3·33	3·05	3·48	2·88
Alumina . . .	0·31	0·14	1·90	0·30	0·66
Oxide of Iron . .	—	—	0·63	0·30	—
Oxide of Manganese .	—	—	—	—	—
Silica . . .	27·72	3·61	14·73	3·30	5·00
Sulphuric Acid . .	3·53	4·47	3·53	4·04	3·41
Phosphoric Acid .	0·25	6·57	5·05	13·07	9·16
Chlorine . . .	0·06	3·62	2·11	3·18	1·57
	52·86	74·78	91·32	95·53	69·57

The above quantities are contained in a thousand pounds of the dry hay of each plant.

On comparing the numbers opposite to potash, lime, magnesia, alumina, silica, and phosphoric acid, we see very striking differences in the quantities of these substances, contained in equal weights of the above different kinds of hay. These differences lead to very important practical inferences in reference,—

1°. To the kind of soil in which each will grow most luxuriantly.

2°. To the artificial means by which the growth of each may be promoted—in so far as this growth depends upon the supply of inorganic food to the growing plant.

3°. To the feeding properties of each, and to the *kind* of stock they are severally most fitted to nourish.

To these and other important practical deductions suggested by the above tabulated analyses—as well as by those previously given—of the inorganic matters contained in the several varieties of vegetable productions usually raised for food, we shall hereafter have frequent occasion to revert. In the mean time, a preliminary enquiry demands our attention, which we shall proceed to consider in the following section.

§ 3. *To what extent do the crops most usually cultivated, exhaust the soil of inorganic vegetable food?*

A bare inspection of the tabular results exhibited in the preceding section, gives but a faint idea of the extent to which the inorganic elementary bodies are necessarily withdrawn from the soil in the ordinary course of cropping.

I. Let us consider the effect upon the soil of a still too common three years' course of cropping—*fallow*, *wheat*, *oats*.* If the produce of such a course be 25 bushels of wheat and 50 bushels of oats, there would be carried from the soil every three years in pounds—

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* Common, among other counties, in that of Durham. There are cases, however, in which this three years' course may not be indefensible, and it never could be compared with some of the so-called *improved* rotations in East Lothian in the time of Lord Kames; as for instance, *fallow*, *barley*, *clover*, manure on the clover stubble, then *wheat*, *barley*, *oats*.—See *The Gentleman Farmer* (1802), p. 147.

	WHEAT.		OATS.		Total.
	Grain.	Straw.	Grain.	Straw.	
Potash . .	3·3	0·6	3·75	32·7	40·35
Soda . .	3·5	0·9	3·3	—	7·7
Lime . .	1·5	7·2	2·5	5·7	16·9
Magnesia . .	1·5	1·0	1·7	0·8	5·0
Oxide of Iron .	—	—	1·0	—	1·0
Silica . .	6·0	86·0	50·0	172·0	314·0
Sulphuric Acid .	0·75	1·0	0·9	3·0	5·65
Phosphoric Acid .	0·6	5·0	1·43	0·5	7·53
					398·13

The gross weight carried off in these crops is large—amounting to about 400 lbs. It will vary, however, with the kind of wheat and oats which are grown, and may often be greater than this.* The greatest portion of the matter carried off, however—upwards of three-fourths of the whole—consists of silica; the rest of the materials are equal to

60 lbs. of dry pearl-ash,
36 lbs. of the common soda of the shops,
28 lbs. of bone-dust,
12 lbs. of gypsum,
5 lbs. of quick-lime,
5 lbs. of magnesia,—or for the last three may be substituted 33 lbs. of common Epsom salts and 17 lbs. of quick-lime.

The form in which the silica may be restored to the soil in a state in which the plant can absorb it, will be considered hereafter.

Though large as a whole, the weight of each of the ingredients, taken singly, is not great; and yet it is not difficult to understand that if a constant drain be kept up on the soil year after year, and the practical farming adopted is of such a kind as *not* to restore to the soil a due proportion of *each* of the substances carried off—the time must come when, under ordinary circumstances, the soil will no longer be able to supply the demands of a healthy and luxuriant vegetation.

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* See the following section (§ 4) of the present Lecture.

II. Let us next consider the effect of a four-course system in withdrawing these inorganic substances from the soil. And for this purpose let us adopt one suited to the lighter soils—as to that of Norfolk—*turnips, barley, clover and rye grass, wheat.*

Let the crop of turnips amount to 25 tons of roots per acre, of barley to 38 bushels, of clover and rye grass each to one ton of hay, and of wheat as before to 25 bushels. Then we have from the entire rotation in pounds—

	Turnip Roots.	BARLEY.		Red Clover.	Rye Grass	WHEAT.		Total.
		Grain	Straw			Grain	Straw	
Potash . .	145·5	5·6	4·5	45·0	28·5	3·3	0·6	233·0
Soda . .	64·3	5·8	1·1	12·0	9·0	3·5	0·9	96·6
Lime . .	45·8	2·1	12·9	63·0	16·5	1·5	7·2	149·0
Magnesia .	15·5	3·6	1·8	7·5	2·0	1·5	1·0	32·9
Alumina . .	2·2	0·5	3·4	0·3	0·8	0·4	2·7	10·3
Silica . .	23·6	23·6	90·0	8·0	62·0	6·0	36·0	299·2
Sulphuric Acid	49·0	1·2	2·8	10·0	8·0	0·8	1·0	72·8
Phosphoric do .	22·4	4·2	3·7	15·0	0·6	0·6	5·0	51·5
Chlorine .	14·5	0·4	1·5	8·0	0·1	0·2	0·9	25·6
								970·9*

On comparing the numbers in the last column—containing the total quantities of matter abstracted—with those contained in the three years' rotation (p. 325), we see how very much larger an addition must be made to the land every fourth year, if we are to restore to it any thing like an equivalent for the inorganic matter carried off.

It will be especially observed that the quantity of potash, and of soda, and indeed of nearly every ingredient except the silica, carried off in this course of cropping, is much greater, even in proportion to the time it occupies, than in the three-year shift—and that *nine-tenths of the potash and soda withdrawn from the soil are contained in the green crops.*

To place the relative effect of the green and corn crops upon the soil in a clearer light, I shall exhibit the several quantities of common and *artificial* salts and manures which it would be necessary to add to each acre at the beginning of this rotation, in order to supply the various inorganic substances about to be taken from the land in the next four years' cropping. These quantities are as follow, in pounds :—

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* This is exclusive of the turnip tops, which I have omitted, from not knowing what proportion their weight in the green state generally bears to that of the roots.

	Total.	For the Green Crops.	For the Corn Crops.
Dry Pearl-ash . - -	325	316	9
Crystallized Carbonate of Soda*	333	290	43
Common Salt - - -	43	38	5
Gypsum - - - - -	—	30	—
Quick-lime - - - -	150	100	7
Epsom Salts - - - -	200	150	50
Alum - - - - -	83	27	56
Bone-dust - - - -	210	150	60

With the exception of the silica, the substances above-named, in the quantities given, will replace all the inorganic matters contained in the whole crop reared, the turnip tops alone not included. A single glance at the second and third columns shows how much greater a proportion of all these substances is necessary, to return what the green crops have taken from the land.

That the fertility of the soil depends in some considerable degree on the quantity of the alkaline and other compounds present in it, there can be no question,—since not only do we find extraordinary natural luxuriance of vegetation where some of these happen to be present in the soil, but we can often greatly increase the apparent productiveness of our fields by spreading such substances over them in sufficient quantity.

How comes it, then, that the green crops which carry off all these substances in the greatest quantity by very much, should yet least injure the land,—nay, should rather renew and prepare it again for the growth of crops of corn?

This is one of the most interesting practical questions which can present itself to us in the existing state of theoretical agriculture ;—but it would carry us away from our more immediate object, were we prematurely to enter upon the discussion of it in this place. It will hereafter demand our especial attention, when we shall have become familiar with the nature and origin of soils.

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* Or for every 100 lbs. of the common carbonate of soda may be substituted 40 lbs. of common salt or 60 lbs. of dry nitrate of soda.

I may be permitted, however, to draw your attention here for a moment—as neither out of place, nor uninteresting, for many reasons,—to an opinion expressed by Liebig on the question *why wheat prefers stiff and clayey soils.* "Again," he says, "how does it happen that wheat does not flourish in a sandy soil, and that a calcareous soil is also unsuitable for its growth, unless it be mixed with a considerable quantity of clay? It is because these soils do not contain alcalies in sufficient quantity, the growth of wheat being arrested by this circumstance, even should all other substances be presented in abundance."[*]

Without dwelling on the fact that excellent crops of wheat are reaped in some parts of our island from sandy and calcareous[†] soils—what kind of crops, we may ask, can be reared with success on the lighter soils to which wheat seems least adapted? The turnip rejoices in light land, and the potatoe not unfrequently attains the greatest perfection on a sandy soil. Yet ten tons of potatoe roots, or twenty of turnip bulbs,—exclusive of the tops—contain *nearly ten times* as much of the two alcalies, potash and soda, as fifty bushels of wheat with its straw included.[‡] What ground is there, then, for the explanation given by Liebig—of the peculiar qualities of the so-called wheat lands? We might with far greater show of reason assume the converse of his proposition, and infer that wheat does not prefer sandy soils *because they are too rich in alkali!* It is singular, and would almost seem to strengthen this converse proposition, that beans, peas, and vetches, which are so often resorted to as a good preparative for wheat, contain also a much larger quantity of alkali than the latter grain. Thus the grain and straw together of twenty-six bushels of beans contain 71 lbs., of twenty bushels of peas 26 lbs., and of twenty bushels of vetches 74 lbs. of potash and soda taken together.

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[*] *Organic Chemistry applied to Agriculture*, p. 151.

[†] On the thin chalk soils of the Yorkshire Wolds a crop of wheat is taken every four or five years, yielding an average of 24 or 25 bushels. The rotation is turnips, barley, clover or beans, wheat.

[‡] According to the analyses of Sprengel given in the previous pages, ten tons of potatoes contain 143 lbs. of alcalies, twenty tons of turnips 154 lbs., and fifty bushels of wheat with its straw only 16 lbs.

As I have already stated, however, we are not yet prepared for discussing this very curious and interesting question.

§ 4. *Of the alleged constancy of the inorganic constituents of plants, in kind and quantity.*

In the preceding lecture (ix. p. 260), it was stated that the ash of the same plant, if ripe and healthy, is nearly the same in kind and quality in whatever circumstances (if favourable) of soil and climate it may grow. This *general* observation, however, is consistent with certain differences in the above respect, which are not without interest in their bearing upon agriculture both in theory and practice. Thus

1°. The different parts of the same plant contain quantities of inorganic matter, not only different in their gross weights, but unlike also in the relative proportions of the several substances of which the entire ash consists. Both of these points have been previously illustrated (pp. 262, 264), and they are placed in the clearest light by the tabulated analyses introduced into the preceding section.

2°. The quantity and relative proportions of the different inorganic substances also vary with the season of the year at which the examination is made. Thus according to De Saussure, plants of the same wheat which a month before flowering left 7·9 per cent. of ash, left when in flower only 5·4, and when ripe 3·3 per cent. The quantity of potash in the potatoe leaf diminishes very much as the plant approaches to maturity (Mollerat)—and the same has been observed in many saltworts and other sea-side plants. In the young plant of the *salsola clavifolia* there is much potash and no soda, but as its age increases the latter alkali appears, and gradually takes the place of the former.*

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* Meyen, *Jahresbericht*, 1839, p. 125. In regard to these salt-loving plants, which generally abound in soda, a curious observation was long ago made by Cadet. He states that if a plant of common saltwort (*salsola sali*) be transplanted into an inland district—and seed

It is probably true, therefore, of all plants—that the ash both in kind and quantity is affected by the age at which the plant has arrived. It would appear that the unlike chemical changes which take place in the interior of the plant, at the successive periods of its growth, require the presence of different chemical agents—or that the production of new parts demands the co-operation of new substances.

3°. Similar differences are sometimes observed also when the same plant is grown in different soils. Thus it is known that the straw of the oat grown upon boggy land is very different in colour and lustre, from that yielded by the same variety of seed, when grown upon sound and solid soil. I lately examined two such portions of straw from the same seed—grown on the same farm on the estate of Dunglass, the one on boggy, the other on sound stiff land, when the straw from the

Sound land left 6·64 per cent. of ash, and from the
Boggy land ......6·2 per cent. of ash;

while the *silica* contained in the ash from the

Sound land amounted to 3·42 per cent., and from the
Boggy land..............to 1·90 per cent. of the weight

of the straw.

A remarkable difference, therefore, existed in the relative proportions, at least of the silica, in these two varieties of straw, and this difference can be attributed only to the unlike nature of the soils in which the two samples were grown. But on boggy soils the oat plant is unhealthy, and in general neither fills its ear, nor ripens a perfect seed;—the difference in the ash in this case, therefore, cannot be considered as entirely opposed to the general proposition, that in a *healthy* state, plants at the same period of their growth always yield nearly the same weight of ash.

from this plant be afterwards sown, the second race of plants will contain much potash, but scarcely a trace of soda. Gmelin's, *Handbuch der Chemie, II.*, p. 1492. Potash may thus take the place of soda for a time, but removed from its native *habitat*, the plant would in a few generations die out and disappear.

But that different experimenters have obtained very unlike quantities of ash, from the most common cultivated plants, apparently in a state of health, when grown under different circumstances of soil and climate,—does appear to contradict this general proposition. Thus 100 lbs. of *ripe wheat straw* leave of ash

4·3 lbs. de Saussure;	4·4 lbs. Berthier;
3·5 lbs. Sprengel;	15·5 lbs. Sir H. Davy;

while the straw of one variety of red wheat grown on a clay-loam, at Aykley Heads, near Durham, gave me 6·6 per cent., and that of two other varieties of red wheat, grown near Dalton, in Ravensworth Dale, Yorkshire, a country abounding in limestone—and on the same field—left respectively 12·15 and 16.5 per cent. of ash. The difference of 4 per cent. between these last two results, shows that the quantity of ash depends much upon the *variety* of grain examined—though to what extent all the great differences obtained, as above shown, are to be ascribed to this cause alone, it is impossible to say, until numerous other experiments shall have been instituted.

One thing, however, is manifest, that the quantities of inorganic matter necessarily contained in a crop of wheat, given in a previous page (p. 318) on the authority of Sprengel, must be considered as probably far below the mean proportion, since some varieties yield, in the form of ash, about six times as much as is there stated.

Every one knows how uncertain general conclusions are, —or explanations of natural phenomena,—when deduced from single observations only, and of this truth the above results present us with a useful illustration. Thus Liebig, in his *Organic Chemistry applied to Agriculture* (p. 152), to which we have had frequent occasion to refer—explains why land will refuse to grow wheat, and may yet produce good crops of oats or barley in the following manner:— "One hundred parts of the stalks of wheat yield 15·5 parts of ashes (H. Davy): the same quantity of the dry stalks of barley 8·54 (Schrader), and one hundred parts of the stalks of oats only 4·42. The ashes of all are of the same composition. We have in these facts a clear proof of what plants require for their growth. Upon the same field which will yield only one harvest of wheat, two crops of barley and three of oats may be raised."

In this passage it has been assumed that the ash of wheat and other straws is constant in quantity, that wheat straw always contains much more than that of oats or barley, and that the *ash is in each case of the same composition* (see above, pp. 318 to 320),—all of which premises being incorrect, the conclusion must of course be rejected.

But the straw of barley and oats also, according to different authorities, leaves very unlike quantities of ash. Thus, according to Sprengel and Schrader, 100 lbs. of

	Sprengel.	Schrader.	
Oat straw leave......	5·74 lbs.	4·42 lbs. ;	6·6 J.
Barley straw.........	5·24 lbs.	8·54 lbs. ;	

we cannot help conceding, therefore, generally, in regard to the cereal grasses, *that different* VARIETIES, at least, *of the same plant, may contain inorganic matter in different proportions*.

But certain analyses which have been made seem to demand a still further concession. Thus De Saussure found that the ash left by the same tree or shrub—by the fir or the juniper for example—differed both in kind and in quantity, according as it grew upon a granitic or calcareous soil. Berthier also found the ash of a piece of Norway pine (*pinus abies*) to differ very much from that of the wood of the same pine grown in France. From these and a few other observations, the conclusion has been very generally drawn by vegetable physiologists, that the ash of plants in general is determined both in kind and quantity *by the soil in which they grow*.

This is very likely to be true to a *certain extent*, as we have seen in the straw of the bog oat above adverted to, but a sufficient number of accurate comparative analyses of the ash of cultivated plants* has not yet been published, to enable us to determine the precise influence of the soil in all cases. It is impossible, however, that the prevailing character of the soil can have more than a *general influence* on the character of the ash of any living vegetable—*so long as the plant retains a healthy state.* The experiments of De Saussure do not appear to have been made with sufficient care,* while the only comparative experiment of Berthier is open to objections of another kind.

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* Five samples of the same variety of wheat (Hunter's wheat) grown on different soils in the neighbourhood of Haddington, gave

I have said that the quantity and kind of the ash is likely to be affected by the character of the soil to a *certain extent.* The following considerations seem to embody nearly all the sources of such variation, of which we can at present speak with any degree of certainty ;—

1°. Plants at different periods of their growth require for the production of their several parts, and therefore appropriate from the soil different inorganic substances ;† hence the ash will vary with the age of the plant.

2. If the substances necessary for the perfection of one or more parts of a plant abound in the soil, its chief develop-

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me very nearly the same proportions of ash. Thus the sample grown on a

	Per cent.
1°. Deep reddish clay loam, *subsoil* gravel, left	1·776
2°. Red clay on gravel	1·787
3°. Stiff clay on retentive subsoil . . .	1·903
4°. Light clay on rather retentive subsoil .	1·917
5°. Light turnip land	1·824

These results approach very near each other. The differences are perhaps too slight to justify us in concluding that the ash is greatest in quantity when the subsoil is most retentive.

* The accuracy of De Saussure's analyses is rendered very doubtful by the fact that, in the ash of *all* the different trees and shrubs he examined, he found a large quantity, in that of the juniper as much as 43 per cent. of *alumina*, and in that of the pine from 12 to 16 per cent., while Berthier, whose skill is undisputed, found no alumina in the ash of any of the numerous trees on which his experiments were made.

† This fact indicates an exceedingly interesting field of chemical research in connection with practical agriculture. What substance will bring this or that seed into early leaf?—what will hasten its growth in middle life?—what will bring it to early maturity? The wheat stalk and the potatoe require more potash while in rapid growth. This growth may be continued and prolonged by the presence of ammonia; while lime is said to bring it sooner to a close, and to give an earlier harvest. How valuable would be the multiplication of such facts!

ment will take the direction of those parts. Thus one plant will run to leaf or straw, another to flower and seed. Thus also in the grain of one crop of wheat more gluten is produced than in that of another, and as this gluten appears to contain the phosphates of lime and magnesia, as essential constituents, the ash will necessarily vary with the gluten of the seed.

3°. Some substances appear to enter into the circulation of plants not so much as actual and necessary constituents of the parts of the vegetable, as to serve as media or agents by which other compounds, both organic and inorganic, may be conveyed to the plant. Thus common salt appears to enter many plants for the purpose of supplying soda, its chlorine being discharged by the leaf. Silica enters the plant chiefly in the form of silicate of potash or soda. When it reaches its proper destination—the stalks of the grasses for instance—this silicate is decomposed chiefly by the carbonic acid, which is always present in the pores of the green stem, the silica is deposited and the alkali proceeds downwards with the sap as a soluble carbonate, or in combination with some other organic acid. Thus the same portion of alkali may return many times into the circulation with this or with other materials which the parts of the plant require, and every new burden it deposits will necessarily cause a new variation in the relative proportions of the several inorganic constituents which are afterwards detected in the ash.

4°. As the water which enters by the roots always brings with it some soluble substances, the quantity of these conveyed into the plant will be materially affected by the amount of evaporation from the leaves; and hence, after a long drought, the leaves of the turnip, the potatoe, and other plants, will yield a larger proportion of ash than will be obtained from them in moist and rainy weather.

5°. In the mineral kingdom it is found that one substance may not unfrequently take the place, and perform the functions of another. Thus potash and soda *replace* each other in certain minerals, as do also lime and magnesia and the phosphoric and arsenic acids. It has been supposed that a similar interchange may take place in the vegetable kingdom—that when the plant cannot get potash it will take soda—that when it can get neither, it will appropriate lime, and so on. Such a conjectural interchange may possibly take place in a small degree, for a limited time, and in certain plants, without materially affecting their apparent health—but it is not by trusting to such resources of nature that a luxuriant vegetation or plentiful crops will ever be reared by the practical agriculturist.

Admitting, however, all these sources of variation in the kind and quantity of the ash obtained from different plants, the sound practical conclusions from all we know on the subject at present seem to be—

1°. That certain inorganic substances, in certain proportions, are necessary to all plants usually cultivated for food —if they are to be reared or maintained in a *healthy* state.

2°. That we must seek for these *necessary* substances in the inorganic constituents which are present in the richest crops of every kind—in the produce of the most fertile soils.*

3°. That where these necessary substances are not present in any soil, we may infer that it will prove unfit to yield a luxuriant crop of a given kind; or, on the other hand, where these substances are not to be detected in the ash of the plant, that the fault of the crop, if any, may be ascribed to their partial or total absence from the soil on which it grew.

These conclusions form the basis of an enlightened and scientific practical agriculture. This basis, however, requires to be strengthened and enlarged by further experimental investigations.

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* "I have examined," says Sprengel. "the finest seed-corns from many localities, and I have invariably found the quantities not only of the organic substances—starch, sugar. &c.—but also of the inorganic compounds in all the celebrated seed-corns, so perfectly alike, that one would have thought they had all grown on one and the same soil."—*Lehre vom Dünger*, p. 43.

LECTURE XI.

Nature and origin of Soils.—Organic matter in the soil.—General constitution of the earthy part of the soil.—Classification of soils from their chemical constituents.—Method of approximate analysis for the purposes of classification.—General origin of soils and subsoils.—Structure of the earth's crust.—Stratified and unstratified rocks.—Crumbling or degradation of rocks.—Diversity of soils produced.—Superficial accumulations.—Tabular view of the character and agricultural capabilities of the soils of the different parts of Great Britain.

Such are the inorganic compounds which minister to the growth of plants, and such the proportions in which they severally occur in the living vegetable. Whence are these inorganic constituents all derived?

We have seen that the atmosphere, when pure, contains no inorganic matter, and that if dust, spray, or vapours occasionally float in the air, and are carried by the winds to great distances—yet that they are only accidentally present, and cannot be regarded as a source from which the general vegetation of the globe derives a constant supply of those mineral substances which are necessary to its healthy existence.

The soil on which they grow is the only natural source from which their inorganic food can be derived. We are led, therefore, as the next subject of our study, to enquire into the *nature* and *origin* of soils.*

§ 1. *Of the organic matter in the soil.*

Soils differ much as regards their immediate origin, their physical properties, their chemical constitution, and their agricultural capabilities; yet all soils which in their existing state are capable of bearing a profitable crop, possess one common character—they all contain *organic* matter in a greater or a less proportion.

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* On the subject of this and the following lecture, the reader will consult with advantage an excellent little work, "*On the nature and property of soils*," by Mr. John Morton.

This organic matter consists in part of decayed animal, but chiefly of decayed vegetable substances, sometimes in brown or black fibrous portions, exhibiting still, on a careful examination, something of the original structure of the organized substances from which they have been derived—sometimes forming only a fine brown powder intimately intermixed with the mineral matters of the soil—sometimes scarcely perceptible in either of those forms, and existing only in the state of organic compounds more or less void of colour and at times entirely soluble in water. In soils which appear to consist only of pure sand, or clay, or chalk, organic matter in this latter form may often be detected in considerable quantity.

The proportion of organic matter in soils which are naturally productive of any useful crops, varies from one-half to 70 per cent. of their whole weight. With less than the former proportion they will scarcely support vegetation—with more than the latter, they require much admixture before they can be brought into profitable cultivation. It is only in boggy and peaty soils that the latter large proportion is ever found—in the best soils the organic matter does not average five per cent., and rarely exceeds ten or twelve. Oats and rye will grow upon land containing only one or one and a half per cent.—barley where two or three per cent. are present—but good wheat soils contain in general from 4 to 8 per cent., and, if very stiff and clayey, from 10 to 12 per cent. may occasionally be detected.

Though, however, a certain proportion of organic matter is always found in a soil distinguished for its fertility, yet the presence of such substances is not alone sufficient to impart fertility to the land. I do not allude merely to such as like peaty soils contain a very large excess of vegetable matter, but to such also as contain only an average proportion. Thus of two soils in the same neighbourhood—the one contained 4·05 per cent. of organic matter, and was very fruitful—the other 4·19 per cent., and was almost barren. This fact is consistent with what has been stated in the two preceding lectures, in regard to the influence exercised by the dead *inorganic* matter of the soil, on the general health and luxuriance of vegetation.

§ 2. *General constitution of the earthy part of the soil.*

From what is above stated, it appears that, on a general average, the earthy part of the soil in our climate does not constitute less than 96 per cent. of its whole weight, when free from water. This earthy part consists principally of three ingredients:—

1°. Of *Silica*, siliceous sand, or siliceous gravel—of various degrees of fineness, from that of an inpalpable powder as it occurs in clay soils, to the large and more or less rounded sandstones of the gravel beds.

2°. *Alumina*—generally in the form of clay, but occasionally occurring in shaly or slaty masses more or less hard, intermingled with the soil.

3°. *Lime*, or carbonate of lime—in the form of chalk, or of fragments more or less large of the various limestones that are met with near the surface in different countries. Where cultivation prevails it often happens that all the lime which the soil contains has been added to it for agricultural purposes—in the form of quick-lime, of chalk, of shell sand, or of one or other of the numerous varieties of marl, which different districts are known to produce.

It is rare that a superficial covering is any where met with on the surface of the earth, which consists solely of any one of these three substances—a soil, however, is called *sandy* in which the siliceous sand greatly predominates, and *calcareous*, where, as in some of our chalk and limestone districts, carbonate of lime is present in considerable abundance. When alumina forms a large proportion of the soil, it constitutes a *clay* of greater or less tenacity.

The term *clay*, however, or *pure clay*, is never used by writers on agriculture to denote a soil consisting of alumina only, for none such ever occurs in nature. The pure *porcelain clays* are the richest in alumina, but even when free from water they contain only from 42 to 48 per cent. of this earth, with from 52 to 58 of silica. These occur, however, only in isolated patches, and never alone form the soil of any considerable district. The strongest clay soils which are any where in cultivation rarely contain more than 35 per cent. of alumina.*

Soils in general consist in great part of the three substances above named in a state of *mechanical mixture*. This is always the case with the siliceous sand and with the carbonate of lime—but in the clays the silica and the alumina are, for the most part, in a state of *chemical combination*. Thus, if a portion of a stiff clay soil be kneaded or boiled with repeated portions of water till its coherence is entirely destroyed, and if the water, with the finer parts which float in it, be then poured into a second vessel, the whole of the soil will be separated into two portions—a fine impalpable powder consisting chiefly of clay, poured off with the water, and a quantity of siliceous or other sand in particles of various sizes, which will remain in the first vessel. This sand was only mechanically mixed with the soil. The fine clay retains still some mechanical admixtures, but consists chiefly of silica and alumina chemically combined.

Of the porcelain clays above alluded to, there are several varieties, three of which, containing the largest proportion of alumina, consist respectively of—

	I.	II.	III.
Silica . .	47·03	46·92	46·0
Alumina. .	39·23	34·81	40·2
Water . .	13·74	18·27	13·8
	100·00	100·00	100·0†

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* In an interesting paper on subsoil ploughing by Mr. H. S. Thompson, in the report of the Yorkshire Agricultural Society for 1837, p. 47, it is stated that the lias clays, which form the subsoil in certain parts of Yorkshire, contain sometimes, *in the dry state, as much as 54 per cent. of alumina* (?)

† When heated to redness the whole of the water is driven off from these clays, and they then consist respectively of—

Silica	54·5	57·4	53·4
Alumina . . .	45·5	42·6	46·6
	100·0	100·0	100·0

which numbers are in accordance with those given at the foot of the preceding page.

But, as already stated, these clays rarely form a soil—the stiffest clays treated by the agriculturist containing a further portion of silica, some of which is mechanically mixed, and can be partially separated by mechanical means.

The strongest agricultural clays (*pipe-clays*) of which trustworthy analyses have yet been published, consist, in the dry state, of 56 to 62 of silica, from 36 to 40 of alumina, 3 or 4 of oxide of iron, and a trace of lime. Clays of this composition are distinguished by the foreign agricultural writers as *pure clays*. They are all probably made up of some of the varieties of porcelain clay, more or less intimately mixed with siliceous and ochrey particles—in so minute a state of division that they cannot be separated by the method of decantation above described.

These *clays* are adopted by the German and French writers as a standard to which they can liken clay soils in general, and by comparison with which they are enabled distinctly to classify and name them. As the use of the term *clay* in this sense has been introduced into English agricultural books,* and as it is really desirable to possess a word to which the above meaning can be attached, I shall venture in future to employ it always strictly in this *agricultural sense*.

By alumina, then, I shall in all cases express the pure earth of alum, which exists in clays, and to which they owe their tenacity—by CLAY, *a finely divided chemical compound, consisting very nearly of* 60 *of silica and* 40 *of alumina, with a little oxide of iron, and from which no siliceous or sandy matter can be separated mechanically or by decantation.*

Of this clay the earthy part of all known soils is made up by mere mechanical admixture with the other earthy constituents (sand and lime), in variable proportions. On a knowledge of these proportions the following general classification and nomenclature are founded.

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* As in *British Husbandry*, p. 113, and in *Loudon's Encyclopædia of Agriculture*, p. 315, where classifications of soils are given chiefly from Von Thaer, though neither work exhibits with sufficient prominence the meaning to be attached to *agricultural clay*, as distinguished from alumina, sometimes called *pure clay* by the chemist.

§ 3. *Of the classification of soils from their chemical constituents.*

Upon the principles above described soils may be classified as follows:—

1°. *Pure clay* (pipe-clay) consisting of *about* 60 of silica and 40 of alumina and oxide of iron, for the *most part* chemically combined. It allows no siliceous sand to subside when diffused through water, and rarely forms any extent of soil.

2°. *Strongest clay soil* (tile-clay, unctuous clay) consists of pure clay mixed with 5 to 15 per cent. of a siliceous sand, which can be separated from it by boiling and decantation.

3°. *Clay loam* differs from a clay soil, in allowing from 15 to 30 per cent. of fine sand to be separated from it by washing, as above described. By this admixture of sand, its parts are mechanically separated, and hence its freer and more friable nature.

4°. A *loamy soil* deposits from 30 to 60 per cent. of sand by mechanical washing.

5°. A *sandy loam* leaves from 60 to 90 per cent. of sand, and

6°. A *sandy soil* contains no more than 10 per cent. of pure clay.

The mode of examining with the view of naming soils, as above, is very simple. It is only necessary to spread a weighed quantity of the soil in a thin layer upon writing paper, and to dry it for an hour or two in an oven or upon a hot plate, the heat of which is not sufficient to discolour the paper—the loss of weight gives the water it contained. While this is drying, a second weighed portion may be boiled or otherwise thoroughly incorporated with water, and the whole then poured into a vessel, in which the heavy sandy parts are allowed to subside until the fine clay is beginning to settle also. This point must be carefully watched, the liquid then poured off, the sand collected, dried as before upon paper, and again weighed. This weight is the quantity of sand in the known weight of *moist* soil, which by the previous experiment has been found to contain a certain quantity of water.

Thus, suppose two portions, each 200 grs., are weighed, and the one in the oven loses 50 grs. of water, and the other leaves 60 grs. of sand,—then, the 200 grs. of *moist* are equal to 150 of *dry*, and this 150 of dry soil contain 60 of sand, or 40 in 100 (40 per cent.) It would, therefore, be properly called a *loam*, or *loamy soil*.

But the above classification has reference only to the clay and sand, while we know that lime is an important constituent of soils, of which they are seldom entirely destitute. We have, therefore,

7°. *Marly soils*, in which the proportion of lime is more than 5 but does not exceed 20 per cent. of the whole weight of the dry soil. The marl is a sandy, loamy, or clay marl, according as the proportion of clay it contains would place it under the one or other denomination, supposing it to be entirely free from lime, or not to contain more than 5 per cent., and

8°. *Calcareous soils*, in which the lime exceeding 20 per cent. becomes the distinguishing constituent. These are also calcareous clays, calcareous loams, or calcareous sands, according to the proportion of clay and sand which are present in them.

The determination of the lime also, when it exceeds 5 per cent., is attended with no difficulty.

To 100 grs. of the dry soil diffused through half a pint of cold water, add half a wine glass-full of muriatic acid (the spirit of salt of the shops), stir it occasionally during the day, and let it stand over night to settle. Pour off the clear liquor in the morning and fill up the vessel with water, to wash away the excess of acid. When the water is again clear, pour it off, dry the soil and weigh it—the loss will amount generally to about one per cent. more than the quantity of lime present. The result will be sufficiently near, however, for the purposes of classification. If the loss exceed 5 grs. from 100 of the dry soil, it may be classed among the marls, if more than 20 grs. among the calcareous soils.

Lastly, vegetable matter is sometimes the characteristic of a soil, which gives rise to a further division of

9°. *Vegetable moulds*, which are of various kinds, from the garden mould, which contains from 5 to 10 per cent., to the peaty soil, in which the organic matter may amount to 60 or 70. These soils also are clayey, loamy, or sandy, according to the predominant character of the earthy admixtures.

The method of determining the amount of vegetable matter for the purposes of classification, is to dry the soil well in an oven, and weigh it; then to heat it to dull redness over a lamp or a bright fire till the combustible matter is burned away. The loss on again weighing is the quantity of organic matter.

Summary.—The several steps, therefore, to be taken in examining a soil with the view of so far determining its constitution as to be able precisely to name and classify it, will be best taken in the following order:—

1°. Weigh 100 grains of the soil, spread them in a thin layer upon white paper, and place them for some hours in an oven or other hot place, the heat of which may be raised till it only does not discolour the paper. The loss is water.

2°. Let it now (after drying and weighing) be burned over the fire as above described. The second loss is organic, chiefly vegetable matter, with a little water, which still remained in the soil after drying.

3°. After being thus burned, let it be put into half a pint of water with half a wine glass-full of spirit of salt, and frequently stirred. When minute bubbles of air cease to rise from the soil on settling, this process may be considered as at an end. The loss by this treatment will be a little more than the true per centage of lime,* and it will generally be nearer the truth if that portion of soil be employed, which has been previously heated to redness.

4°. A fresh portion of the soil, perhaps 200 grs. in its moist state, may now be taken and washed to determine the quantity of siliceous sand it contains. If the residual sand be supposed to contain calcareous matter its amount may readily be determined by treating the dried sand with diluted muriatic acid, in the same way as when determining the whole amount of lime (3°.) contained in the unwashed soil.†

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* A more rigorous method of determining the lime when less than 5 per cent. will be given in the following lecture.

† The weighings for the purposes here described may be made in a small balance with grain weights, sold by the druggists for 5s. or 6s., and the vegetable matter may be burned away on a slip of sheet iron or in an untinned iron table spoon over a bright cinder or charcoal

Let me illustrate this by an example.

Example.—Along the outcrop of some of the upper beds of the green sand in Berkshire, Wiltshire, and Hampshire, and probably also in Buckingham and Bedford, occur patches of a loose friable *grey* soil mixed with occasional fragments of flint, which is noted for producing excellent crops of wheat every other year. It is known in the valley of Kingsclere, at Wantage, and Newbury. I select a portion of this soil from the latter locality for my present illustration.

1°. After being dried in the air, and by keeping sometime in paper, it was exposed for some hours to a temperature sufficient to give the white paper below it a scarcely perceptible tinge: by this process 104½ grs. lost 4 grs.

2°. When thus dried, it was heated to dull redness. It first blackened, and then gradually assumed a pale brick colour, the change, of course, beginning at the edges. The loss by this process was 4⅓ grs.

3°. After this heating, it was put into half a pint of pure rain water with half a wine glass-full of spirit of salt. After some hours, when the action had ceased, the soil was washed and dried again at a dull red heat. The loss amounted to 3 grs.

The soil, therefore, contained—

Water	4	grs.
Organic matter (less than) .	4⅓	
Carbonate of lime (less than) .	3	
Clay and sand . . .	93⅙	
	104½	

4°. By boiling and washing with water 291 grs. of the undried soil left 202½ grs. of very fine sand chiefly siliceous,—

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fire—care being taken that no scale of oxide, which may be formed on the iron, be allowed to mix with the soil when cold, and thus to increase its weight. Those who are inclined to perform the latter operation more neatly, may obtain for about 6s. each—from the dealers in chemical apparatus—thin light platinum capsules from 1 to 1½ inches in diameter, capable of holding 100 grs. of soil—and for a few shillings more a spirit lamp, over which the vegetable matter of the soil may be burned away. With care, one of these little capsules will serve a lifetime.

104½, therefore, would have left 73 grs., or the soil contained per cent.—

Water	3·9 per cent.
Organic matter (less than) .	4·1
Carbonate of lime (less than) .	3·0
Clay	19·0
Sand (very fine) . . .	70·0
	100·0*

This soil, therefore, containing 70 per cent. of sand, separable by decantation, is properly a *sandy loam.*

§ 4. *Of the distinguishing characters of soils and subsoils.*

Beneath the immediate surface soil, through which the plough makes its way, and to which the seed is entrusted, lies what is commonly distinguished by the name of *subsoil.* This subsoil occasionally consists of a mixture of the general constituents of soils naturally different from that which forms the surface layer—as when clay above has a sandy bed below, or a light soil on the surface rests on a retentive clay beneath.

This, however, is not always the case. The peculiar characters of the soil and subsoil often result from the slow operation of natural causes.

In a mass of loose matter of considerable depth, spread over an extent of country, it is easy to understand how—even though originally alike through its whole mass—a few inches at the surface should gradually acquire different physical and chemical characters from the rest, and how there should thus be gradually established important agricultural distinctions between the first 12 or 15 inches (the soil), the next 15 (the subsoil), and the remaining body of the mass, which, lying still lower, does not come under the observation of the practical agriculturist.

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* Some of these numbers differ by a minute fraction from those in the preceding page: this is because they are calculated from the more correct decimal fractions contained in my own note book. The organic matter is said to be *less than* the number here given, because by simple drying, as here prescribed, the whole of the water cannot be driven off—a portion being always retained by the clay, which is not entirely expelled, till the soil is raised nearly to a red heat. Hence the loss by this second heating must always be greater than the actual weight of organic matter present. The lime is also *less than* the number given, because, as already stated, the acid dissolves a little alumina as well as any carbonate of magnesia which may be present.

On the surface, plants grow and die. Through the first few inches their roots penetrate, and in the same the dead plants are buried. This portion, therefore, by degrees, assumes a brown colour, more or less dark, according to the quantity of vegetable matter which has been permitted to accumulate in it. Into the subsoil, however, the roots rarely penetrate, and the dead plants are still more rarely buried at so great a depth. Still this inferior layer is not wholly destitute of vegetable or other organic matter. However comparatively impervious it may be, still water makes its way through it, more or less, and carries down *soluble organic substances*, which are continually in the act of being produced during the decay of the vegetable matter lying above. Thus, though not sensibly discoloured by an admixture of decayed roots and stems, the subsoil in reality contains an appreciable quantity of organic matter which may be distinctly estimated.

Again, the continual descent of the rains upon the surface soil washes down the carbonates of lime, iron, and magnesia, as well as other soluble earthy substances—it even, by degrees, carries down the fine clay also, so as gradually to establish a more or less manifest difference between the upper and lower layers, in reference even to the earthy ingredients which they respectively contain.

But, except in the case of very porous rocks or accumulations of earthy matter, these surface waters rarely descend to any great depth, and hence after sinking through a variable thickness of subsoil, we come, in general, to earthy layers, in which little vegetable matter can be detected, and to which the lime, iron, and magnesia of the superficial covering has never been able to descend.

Thus the character of the *soil* is, that it contains more brown organic, chiefly vegetable, matter, in a state of decay —of the *subsoil*, that the organic matter is less in quantity and has entered it chiefly in a soluble state, and that earthy matters are present in it which have been washed out of the superior soil—and of the *subjacent mass* that it has remained nearly unaffected by the changes which vegetation, culture, and atmospheric agents have produced upon the portions that lie above it.

From what is here stated, the effect of trench and subsoil ploughing, in altering more or less materially the proportions of the earthy constituents in the surface soil, will be in some measure apparent. That which the long action of rains and frosts has caused to sink beyond the ordinary reach of the plough is, by such methods, brought again to the surface. When the substances thus brought up are directly beneficial to vegetation or are fitted to improve the texture of the soil, its fertility is increased. Where the contrary is the case, its productive capabilities may for a longer or a shorter period be manifestly diminished.

§ 5. *On the general origin of soils.*

On many parts of the earth's surface the naked rocks appear over considerable tracts of country, without any covering of loose materials from which a soil can be formed. This is especially the case in mountainous and granitic districts, and in the neighbourhood of active or extinct volcanoes, where, as in Sicily, streams of naked lava stretch in long black lines amid the surrounding verdure.

But over the greater portion of our islands and continents the rocks are covered by accumulations, more or less deep, of loose materials—sands, gravels, and clays chiefly—the upper layer of which is more or less susceptible of cultivation, and is found to reward the exertions of human industry with crops of corn in greater or less abundance.

This superficial covering of loose materials varies from a few inches to one or two hundred feet in depth, and is occasionally observed to consist of different layers or beds, placed one over the other—such as a bed of clay over one of gravel or sand, and a loamy bed under or over both. In such cases the characters and capabilities of the soil must depend upon which of these layers may chance to be uppermost—

and its character may often be beneficially altered by a judicious admixture with portions of the subjacent layers.

It is often observed, where naked rocks present themselves, either in cliffs or on more level parts of the earth, that the action of the rains and frosts causes their surfaces gradually to shiver off, crumble down, or wear away. Hence at the base of cliffs loose matter collects—on comparatively level surfaces the crumbling of the rock gradually forms a soil—while from those which are sufficiently inclined the rains wash away the loose materials as soon as they are separated, and carry them down to the vallies.

The superficial accumulations of which we have spoken, as covering the rocks in many places to a depth of one or two hundred feet, consist of materials thus washed down or otherwise transported—by water, by winds, or by other geological agents. Much of these heaps of transported matter is in the state of too fine a powder to permit us to say from whence it has been derived—but fragments of greater or less size are always to be found, even among the clays and fine sands, which are sufficient to point out to the skilful geologist the direction from which the whole has been brought, and often the very rocks from which the entire accumulations have been derived.

Thus the general conclusion is fairly drawn, that the earthy matter of *all* soils has been produced by the gradual decay, degradation, or crumbling down of previously existing rocks. It is evident therefore—

1°. That whenever a soil rests immediately upon the rock from which it has been derived, it may be expected to partake more or less of the composition and characters of that rock.

2°. That where the soil forms only the surface layer of a considerable depth of transported materials, it may have no relation whatever either in mineralogical characters or in chemical constitution to the immediately subjacent rocks.

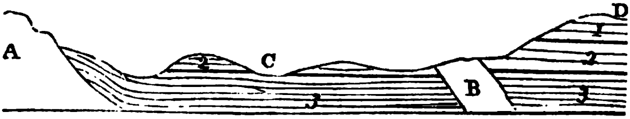
The soils of Great Britain are divisible into two such classes. In some counties an acquaintance with the prevailing rock of the district enables us to predict the general characters and quality of the soil; in others—and nearly all our coal fields are in this case—the general character and capabilities of the soil have no relation whatever to the rocks on which the loose materials rest.

§ 6. *On the general structure of the earth's crust.*

Beneath the soil, and the loose or drifted matters on which it rests, we every where find the solid rock. This rock in most countries is seen—in mines, quarries, and cliffs—to consist of beds or layers of varied thickness placed one over the other. To these layers geologists give the name of *strata;* and hence rocks which are thus made up of many separate layers are called *stratified* rocks.

But in some places entire mountain masses are met with, in which no parting into layers or beds is seen, but which appear to consist of one unbroken rock of the same material from their upper surface downwards, and often as far beneath as we have been able to penetrate into the earth. Such rocks are said to be *unstratified.* Among these are included the granites, the trap, green-stone, or basaltic rocks, and the lavas. Geologists have ascertained that all these unstratified rocks have, like the volcanic lavas, been in a more or less perfectly melted state—that their present appearance is owing to the action of fire—and hence they are often called *igneous** rocks. They often also exhibit a more or less crystalline or glassy structure, or contain, imbedded in them, numerous regular crystals of mineral substances; hence they are sometimes called also *crystalline* rocks. The terms igneous, crystalline, and unstratified, therefore, apply to the same class of rocks—the first indicating their *origin,* the second their structure *in the small,* the third their structure *in the large,* as distinguished from that of the rocks which occur in beds.

The following diagram exhibits the general appearance of the stratified rocks as they are found to occur in contact with unstratified masses in various parts of the globe:—



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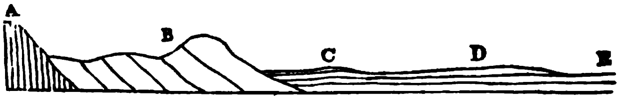
* Sometimes *pyrogenous,* produced by fire; but this is an unnecessarily *hard* word.

A represents an unstratified mountain mass or other similar rock rising up through the stratified deposits. The bending up of the edges of the latter indicates that after the beds were deposited in a nearly level position, the mass A was intruded or forced up through them, carrying the broken edges of the beds along with it.

B shows the more quiet way in which veins or dykes of unstratified green-stone, or trap, or lava, cut through the beds without materially displacing them—as if when in a fluid state it had risen up and filled a previously existing crack or chasm. In Devonshire, in the North of Scotland, and in Ireland, the granite rises in many places exactly as is shown at A, and nearly all our coal fields exhibit in their whin dykes numerous illustrations of what is shown at B.

C and D exhibit the manner in which the strata overlie one another in nearly a horizontal position—1, 2, 3, indicating different kinds of rock,—as a lime-stone, a sand-stone, and a clay—which again are subdivided into beds or thinner layers, by the partings exhibited in the wood-cut.

The stratified rocks lie sometimes nearly level or horizontal over large tracts of country—as in the above diagram,—sometimes they are more or less inclined or appear to dip in one and to rise in the opposite direction—as if a surface, formerly level, had been pushed down at the one end and raised up at the other,—and sometimes they seem to rest entirely upon their edges. Upon the mode in which they thus lie, the *uniformity* of the soil, in a district where it reposes immediately on the rocks from which it is derived, is materially dependent. In the following diagram the surface from A to E



represents a tract of country in which the rocks have in different parts these different degrees of inclination, at A vertical, at B more inclined, and from C to E nearly horizontal. Now, it is obvious that if the outer surface of these several rocks crumble and form a soil which rests where it is produced—then the quality of the soil on every spot will be determined by the nature of the rock beneath. Hence, in proceeding from E over the comparatively level strata, we shall find the soil pretty uniform in quality till we come to the edge of the bed D, thence it will again be uniform, though perhaps different from the former, till we reach the stratum C, when again it will prove uniform over a considerable space till we begin to climb the hill to B. So the whole hill-side in ascending to B will be of one and the same kind of soil. But as we descend on the other side and pass B, we get upon the edges of the beds, and then as we proceed from one bed to another, the quality of the soil may vary every few yards, more or less, according as the members of this group of beds are more or less different from each other. But when we ascend the hill to A, where the beds, besides being vertical, are also very thin, the soil may change at almost every step, provided—which is, however, rarely the case among the rocks (slate rocks) which occur most frequently in this position—provided the mineralogical characters of the several vertical layers be sensibly unlike. Such dissimilarities in the angular position of the strata, as are represented in the above diagram, are of constant occurrence not only in our islands, but in all parts of the globe; and they illustrate very clearly *one* important natural cause of that want of uniformity in the nature and capabilities of the soil which is more or less observable in every undulating and in some comparatively level countries also.

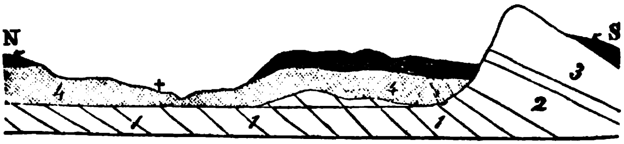
It may be stated, as the general result of an extended examination of all the stratified rocks yet known—that they consist of alternations or admixtures of three kinds of rock only—of sand-stones, of lime-stones, and of clays. The sand-stones are of various degrees of solidity and hardness, from the loose sand of some parts of the lower new-red and green-sand formations, to the almost perfect quartz rock not unfrequently associated with the oldest strata. The lime-stones vary in like manner from the soft chalk to the hard mountain lime-stone and the crystalline statuary marble; while the clays are found of all degrees of hardness from that of the London and Kimmeridge clays, which soften in water, to that of the roofing slates of Cumberland and Wales,—and even to that of the gneiss rocks which rest immediately upon the granite, and which appear to be only the oldest clays altered by the action of heat.

But the stratified rocks, though thus distinguishable into three main varieties—rarely consist of any one of these substances in an unmixed state. The sand-stones not unfrequently contain a little clay or lime—while the lime-stones and clays are often mixed with sand and with each other.

If the stratified rocks thus consist essentially of these three substances, the soils formed from them by natural crumbling or decay must have a similar composition. A sandy soil will be formed from a sand-stone,—a calcareous soil from a lime-stone,—a clay from a slate or shale,—and from a mixed rock, a soil containing a mixture of two or more of these earthy ingredients—in proportions which will depend upon the relative quantities of each which are contained in the rock from which they have been derived.

§ 7. *Relative positions and peculiar characters of the several strata.*

1°. The several strata, or series of strata, which present themselves in the crust of the globe, always maintain the same relative positions. Thus the numbers 3, 2, 1, in the annexed diagram represent three series of beds known by the names of



the magnesian lime-stone, the lower new-red sand-stone, and the coal-measures, lying over each other in their natural positions—the lime-stone uppermost, the sand-stone next, and the coal beneath both. Whenever these three rocks are met with, near each other, they always occupy the same relative position, the coal never appears above this lime-stone, and the sand-stone, if present, is always between the two other series of beds. The same is true of every other group of strata—the order in which they are placed over each other is universally the same.

2°. These beds are generally continuous also over very large areas—or are found to stretch, without interruption, over a great extent of country. Hence when they dip beneath other beds, as they are seen to do in the above diagrams, we can still, with a high degree of probability, infer their presence at a greater or less depth, wherever we observe on the surface those other beds which are known usually to lie immediately above them. Thus, if in a tract of country consisting of the magnesian lime-stone (3) above-mentioned, it is known that deep vallies occur, it becomes probable that the soil in those vallies will rest upon, and may be formed from, the underlying red sand-stones or coal-measures; and that it will therefore possess very different agricultural capabilities from the soil that generally prevails around it. Or in chalk districts, beneath which usually lies the green-sand, the presence of a deep valley cutting through the chalk almost necessarily implies in the hollow a very different soil from that which is cultivated in the chalk wolds above. This is the case in the valley of Kingsclere, where the peculiar wheat soil occurs, of which an approximate analysis has been given in page 344.

3°. It has been already stated that the stratified rocks, though so very numerous and so varied in appearance, yet consist generally of repeated alternations of lime-stones, sand-stones, and clays, or of mixtures of two or more of these earthy substances. But the several series of strata are nevertheless distinguished from each other by peculiar and often well-marked characters.

Thus some are soft, crumble readily, and soon form a soil,—while others, though consisting of the same ingredients, long refuse to break into minute fragments, and thus condemn the surface of the country where they occur to more or less partial barrenness.

In others, again, the proportions of sand or lime are so varied, from bed to bed, that the character of the mixture in each is entirely different—so that while one, on crumbling down, will give a stiff clay, another will produce a loam, and a third a sandy marl.

Or, in some rocks the remains of vegetables are present in considerable quantity,—as in the neighbourhood of our coal-beds—or the bones or shells of animals in greater or less abundance, by each of which the agricultural characters and capabilities of the soils formed from them, will be more or less extensively affected.

Or lastly, the mixture of other earthy substances gives a peculiar character to many rocks. Thus the per-oxide of iron, which imparts their red colour to many strata—as to the red sandstones—influences not only the mineralogical character of the rock, but also the quality of the soil which is formed by its decay. In like manner the presence of magnesia, sometimes in large quantity, in many limestones, produces an important modification in the chemical constitution and mineralogical characters of the rock, as well as in its relations to practical agriculture.

In consequence of these and other similar causes of diversity, if not every stratum, at least every series of strata, exhibits distinguishing and characteristic peculiarities, by means of which it may be more or less readily recognised. On these peculiarities the special agricultural capabilities of those parts of the globe in which each series of beds occurs are in a great degree dependant.

4°. This peculiar character is also more or less continuous over very large areas. Thus if a given stratum be found on the surface in any part of England, and again in any part of Russia, the soil formed from that bed will generally exhibit very nearly the same qualities in both countries. A knowledge of the geology, therefore,—that is, of the kind of rock which appears on the surface in every part of a country—enables us to predict generally the kind of soil which ought to rest upon it, if it be not covered by foreign accumulations; while, on the other hand, a knowledge of the agricultural capabilities of any one district in which certain rocks are known to lie immediately beneath the soil, and of the agricultural practice suited to that district, will indicate the probable capabilities of any other tract in which the same kind of rock is known to appear on the surface, and of the kind of culture which may be most successfully applied to it.

It is evident, then, that a familiar acquaintance with the general characters and relative positions of all the series of strata that have hitherto been observed, and of the classification of rocks considered geologically, to which this knowledge has led, must be fitted to throw much light upon the principles of a general, enlightened, and philosophical agriculture.

§ 8. *Classification of the stratified rocks, their extent, and the agricultural relations of the soils derived from them.*

It is a received principle, I may say rather, an obvious fact, that in the crust of the earth, as in the walls of a building, those layers which lie lowest or undermost have been first deposited, or are the *oldest*. In reference to this their relative age, the stratified rocks are divided into the primary, the first deposited and most ancient—the secondary, which are next in order—and the tertiary, which overlie both.

These three series of strata are again sub-divided into *systems*, and these into minor groups, called *formations*,—the several members of each system and formation having such a common resemblance, either in mineralogical character or in the kind of animal and vegetable remains found in them, as to show that they were deposited under very nearly the same general physical conditions of the globe.

The following table exhibits the names, relative positions, thicknesses, and mineralogical characters of the stratified rocks, in descending order, *as they occur in our islands.* The annexed remarks indicate also the districts where each of these groups of rocks forms the surface, and the general agricultural character of the soils that rest upon them.

I. TERTIARY STRATA—characterised by containing, among other fossils, the remains of animals, which are identical with existing species.

NAME.	THICKNESS.	MINERALOGICAL CHARACTERS.
1°. *Crag.*	50 *ft.*	A mass of rolled pebbles mixed with marine shells—resting on beds of sand and sandy lime-stone; the whole more or less impregnated with oxide of iron.

EXTENT.—The Crag forms a stripe of land a few miles in width in the eastern part of Norfolk and Suffolk, and in the south-eastern part of the latter county. It is a flat, and generally, it is said, a fertile arable district.

2°. *Fresh-water Marls.* } 100 *ft.* Marls and marly lime-stones, with fresh-water shells divided into two series by an estuary deposit, containing marine shells.

EXTENT.—On these beds reposes the soil of the northern half of the Isle of Wight, the only part of England in which they appear at the surface.

3°. *London Clay.* 200 *to* 500 *ft.* Stiff, almost impervious, brown, blue, and blackish clay, rich in marine shells, and containing layers of lime-stone nodules.

EXTENT.—The greater part of the county of Middlesex, the south-eastern half of Essex, and the southern half of Hampshire, rest upon the London Clay.

SOIL.—The soil is naturally strong, heavy, wet, and tenacious, "sticking to the plough like pitch," and shrinking and cracking in dry weather. Where it is mixed with sand, it forms a fertile loam; and hence where the sand of the subjacent plastic clay is easily accessible, it may readily be improved by admixture. Repeated dressings of London manure convert it into rich meadow land, and even where this cannot be obtained, the difficulty and expense of culture have caused a very large portion of it to be retained in pasture. That which is under culture is said to be too strong for turnips and barley, but to grow excellent crops of wheat and beans.

4°. *Plastic Clay.* 300 *to* 400 *ft.* Alternating beds of clay and sand, of various colours and thicknesses. Some of the beds of clay are pure white, and so fine as to be used for making pipes.

EXTENT.—This formation surrounds the London clay with an indented, generally low, and flat belt, of varying breadth, occupying a large space in Hampshire and Dorset, in Essex, Suffolk, and Norfolk,—stretching along the northern part of Kent and Surry, and throwing out arms into Berks, Buckingham, and Hertford.

SOIL.—The soil is very various, the alternate beds of sand and clay of different qualities producing soils of the most unlike quality often within very short distances. The greatest portion of this tract is in arable culture, but there are extensive heaths and wastes in Berks, Hampshire, and Dorset.

In Norfolk and Suffolk, where the lower beds of this sand rest upon chalk, the soil is readily changed, by an admixture with this chalk, into a good sandy loam, which will yield large crops of turnips, barley, and wheat, instead of the heath and bent, its sole original produce. This chalking is generally repeated once in 8 years, at an expense of 50s. an acre. In Hampshire and Berkshire, the same method is adopted with great success, and the rich crops now reaped from Hounslow Heath are the result of this method of improvement.

II. The SECONDARY STRATA—contain *no* animal remains which can be identified with existing species. Those which are found in them are nearly *all* different from those which occur either in the tertiary above or the primary strata below.

A.—CRETACEOUS SYSTEM.

5°. *Chalk.*	600 *ft.*	The upper part softer, and containing layers of flints, with many marine remains. Below, the chalk is harder, and towards the bottom passes into beds of marl—(chalk marl).

EXTENT.—The chalk occupies a very large area in the south-eastern part of the island. It forms a broad band of from 15 to 25 miles in breadth, running north-east and south-west from the extreme south-western part of Dorset, to the extreme north of Norfolk,—it there turns nearly at a right angle, into the centre of Lincolnshire, where it is 10 to 15 miles in breadth, and thence stretches into Yorkshire, in the south-eastern part of which county it covers a large area, and about Flamborough Head attains a breadth of 25 miles. In passing through Berkshire and Surrey, it is partially interrupted by the plastic clay which it embraces on every side; and hence, in following the outline of this formation it encircles with a broad fringe the southern edges of Sussex and Surrey and the northern borders of Kent.

SOIL.—The soils formed from the upper chalk are all more or less mixed with flints, and they produce naturally a very short but excellent sheep pasture. A great portion of this chalk-land in Dorset, Wilts, and Berks has been occupied as a sheep-walk for ages, though under proper cultivation it is said to be convertible into good arable land, producing barley, turnips, wheat, and sainfoin. The lower chalk soils (chalk marl) consist of a deep, strong, calcareous grey or white loam, *very productive*, and when mixed with the green sand below it, becoming still richer, more friable, and more productive of every kind of crop. It is better suited for wheat than the upper chalk, but is less adapted for turnips.

The porous nature of the chalk renders the soil very dry, and in many localities the only method of obtaining a sufficient supply of water is by forming ponds to catch and retain the rain-water.

In Norfolk and Suffolk, on the Lincolnshire, and more recently on the Yorkshire Wolds, great improvement has been erected by dressing the chalk-soil with fresh chalk brought up from a considerable depth below, and laid on at the rate of 50 to 80 cubic yards per acre. The explanation of this procedure is to be found in the fact above stated, that the lower chalk marls, without flints, produce an excellent soil, fitted therefore, by admixture with the poorer upper-chalk soils, for materially improving their quality. It is, therefore, only in localities where this lower chalk can be obtained, that the above method of improvement can be with any material advantage adopted. This is proved by the practice at Sudbury, in Suffolk, which rests upon the upper beds, where it is found to be more profitable to import the lower chalk from

Kent, to lay upon these lands, than to dress them with any of the chalks (only upper beds) which are immediately within their reach.*

6°. *Green Sand.* 500 *ft.*
a Upper, 100.
b Gault, 150.
c Lower, 250.

The upper beds consist of layers of a greenish sand or sandstone, often chalky. The gault is a solid compact mass of an impervious blue clay, sometimes marly. The lower green sand contains a series of ochrey resting on a series of greenish sandy strata. The whole of these beds are in many places full of fossils.

EXTENT.—The Green Sand forms a narrow border round the whole of the northern and western edge of the chalk, except in Yorkshire, where it has not as yet been any where discovered at the surface. It skirts also the southern edge of the chalk in Surrey and Kent, and its eastern boundary in Hampshire, where it attains a breadth of eight or ten miles. It forms likewise the southern portion of the Isle of Wight.

SOIL.—The upper beds, which are the greenest and most chalky, form an open friable soil, easily worked, and of the most productive character. It consists in general of an exceedingly fine sand, mixed with more or less of clay and calcareous matter (see analysis, p. 344), coloured by greenish grains. It is rich and productive of every species of crop, and the peculiar richness of this soil has been remarked not only in England but also in the United States of North America. In some parts of Bedfordshire the soils of this formation form the most productive garden lands in the kingdom. In other localities, again, where the soil is formed from layers of black or of white silvery sand, it produces naturally nothing but heath.

The impervious gault clay forms in Cambridge and Huntingdon "a thin, cold clay soil, which, when wet, becomes as sticky as glue, is most expensive to cultivate as arable land, and naturally produces a poor, coarse pasture." Much of this tract, though unenclosed, is yet generally in arable culture, under two crops and a naked fallow—the enclosed parts are chiefly in pasture, and yield a rich herbage.

The lower green-sand presents itself over a comparatively small surface, is in some localities (Sussex) laden with iron ochre, and is there naturally unproductive.

B.—OOLITIC SYSTEM.

7°. *Wealden.* 950 *ft.*

a Weald Clay,	300
b Hastings Sand,	400
c Purbeck lime-stone,	250

The upper part consists of a fresh-water deposit of brown, blue, or fawn-coloured clay, often marly and almost always close and impervious to water. Beneath this are the iron or ochrey Hastings sands, which again rest upon the Purbeck beds of alternate fresh-water limestones and marls.

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* A rigorous chemical analysis of characteristic specimens of these two chalks might lead to interesting results.

Extent.—The Wealden rocks appear at the surface only in Sussex and Kent, of which they form the entire central portion.

Soil.—The soil formed from the Weald Clay is fine grained and unctuous—often pale coloured, and containing much fine grained siliceous sand. It forms a paste which dries and hardens almost like a brick, so that the roots of plants cannot penetrate it. From the expense of cultivating such land, much of it is in wood (Tilgate Forest), and some is in poor wet pasture. On the whole of this tract, therefore, there is much room for improvement. The Hastings sands produce a poor brown sandy loam which naturally yield only heath and brush-wood. Much of this soil is in pasture, but, under proper cultivation, it yields good crops of all kinds. Where the ruins of the Purbeck marls are intermixed with it, the soil is of a superior quality.

8. *Upper Oolite.* 600 *ft.*
  a Portland Beds, 100.
  b Kimmeridge Clay, 500.

The upper part of this formation consists of the oolite* limestones and calcareous sand-stones long worked at Portland—the lower of the blue slaty or greyish, often calcareous and bituminous beds of the Kimmeridge clay.

Extent.—The Upper Oolite runs north-east along the northern edge of the green sand, from the western extremity of Dorset to the extreme north of Norfolk. It is in general only 2 or 3 miles, but in a few places expands to 6 or 8 miles in breadth. It appears again on the western edge of the green sand in Lincolnshire, and in Yorkshire forms a stripe 5 or 6 miles in breadth, which crosses the country from Helmsley to Filey Bay. In the Isle of Portland also it is found, and it stretches in a narrow stripe along part of the south coast of Dorset.

Soil.—The soil from the Portland rocks, in consequence of the prevalence of siliceous and the absence of clayey matter, produces naturally, or when laid down to grass, only a poor and benty herbage. Its loose and sandy nature makes it also very cheap to work, and hence it is chiefly in arable culture. It is easily affected by drought, but in damp seasons it produces abundant crops—especially in those parts where the soil is naturally mixed with the detritus of the over-lying Hastings sand, and of the calcareous Purbeck beds.

The Kimmeridge clay forms a tough, greyish, impervious, often, however, very calcareous soil and subsoil. From the difficulty of working it, much of the surface over which this formation extends is laid down to grass, and the old pasture land affords excellent herbage. The celebrated pasture lands of the vale of North Wilts rest partly on this clay. The relative thicknesses of the Portland beds and the Kimmeridge clay will readily account for the fact of this clay being spread over by far the greatest part of the area occupied by this formation. In Yorkshire, clay of a great thickness is the only member of this series that has hitherto been observed. On this, as well as on the subjacent Oxford clay, the judicious investment of capital might produce a much greater annual breadth of corn.

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* So named because they consist of small *egg*-shaped granules, like the roe of a fish.

9°. *Middle Oolite.* 500 *ft.*

Upper Calcareous Grit,	100
Coral Rag,	
Calcareous Grit,	
Oxford Clay,	400.
Kelloways Rock,	
Blue Clay,	

The uppermost bed in this formation is a sand-stone containing a considerable quantity of lime—next is a coralline limestone (coral rag) resting upon other sand-stones which contain much lime in their upper, and little or none in their lower beds. Below these is an enormous deposit of adhesive tenacious dark blue clay, frequently calcareous and bituminous, and towards the lower part containing irregular beds of sand-stones and limestones (Kelloways rock) beneath which the clay again recurs.

Extent.—The middle adjoins the upper oolite on the north and west—accompanying it from the extremity of Dorset, into Wilts, Oxford, Huntingdon, Lincolnshire, and Yorkshire. Until it reaches Huntingdon, it rarely exceeds 6 or 8 miles in width, but in this county and in Lincoln it expands to a width of nearly 20 miles. In Yorkshire it nearly surrounds the upper oolite, and on the northern border of the latter formation attains a width from north to south of 6 or 8 miles.

Soil.—The higher beds of both the upper and lower calcareous grits produce good land. They contain lime intermingled with the other materials of the siliceous sand-stone. The upper calcareous grits are no doubt improved by their proximity to the Kimmeridge clay above them, while the lower calcareous grit is in like manner benefitted by the lime of the super-incumbent coral rag. The under beds of both groups are the more gritty, and form a poor, barren, almost worthless soil, much of which in Yorkshire is still unreclaimed. Upon the hills of the coral rag itself occurs the best pasture which is met with in that part of the North Riding of Yorkshire through which this formation extends.

The Oxford clay, which is by far the most important member of this formation, and forms the surface over by far the largest portion of the area occupied by it—produces a close, heavy, compact clay soil, difficult to work, and which is one of the most expensive of all the clays to cultivate. This is especially the case in Bedford, Huntingdon, Northampton, and Lincoln, in which counties, nevertheless, a considerable extent of it is under the plough. In Wilts, Oxford, and Gloucester, it is chiefly in pasture, and as over these districts it assumes the character rather of a clayey loam, the herbage is thick and luxuriant.

The impervious nature of this clay has caused the stagnation of water upon its lower lying portions, the consequent accumulation of vegetable matter, and the formation of bogs. The extensive fens of Lincoln, Northampton, Huntingdon, Cambridge, and Norfolk, rest upon the Oxford clay. This tract of fenny country is 70 miles in length, and about 10 in average breadth. When drained and covered with the clay from beneath, it is capable of being converted into a most productive soil. In Lincolnshire, there are about a million acres of fen, which have their drainage into the Wash, about 50,000 of which are at present irreclaimable, on account of the state of the outlet.

In the neighbourhood of the Kelloways rock the clay becomes more loamy and less difficult to work.

Both in Yorkshire and in the southern districts, the Oxford clay is found to favour the growth of the oak, and hence it is often distinguished by the name of the *oak tree* clay.

10°. *Inferior Oolite.* 600 *ft.*

a Cornbrash,	30.
b Forest Marble,	50.
c Bradford Clay,	50.
d Bath Ooolite,	130.
e Fuller's Earth,	140.
f Inferior Oolite,	200.
g Calcareous Sand,	

Thin, impure, rubbly beds of shelly lime-stone form the upper part of this series. These rest upon alternate beds of oolitic shelly lime-stone and sand-stone, more or less calcareous, having partings of clay; these again upon beds of blue marly clay, immediately under which are the thick beds of the light-coloured oolite lime-stone of Bath. Beneath these follow other beds of blue clay, with Fuller's earth, based upon another oolitic lime-stone, which is followed by slightly calcareous sands.

EXTENT.—This formation commences also at the south-western extremity of Dorset, and runs north-east, swelling out, here and there, and in Gloucester, Oxford, and Northampton attaining a width of 15 to 20 miles. It occupies nearly the whole of these three counties, covers almost the entire area of Rutland, a large portion of the north-east of Leicester, and then, in a narrow stripe, stretches north through Lincoln, and disappears at the Humber. It appears again in the North Riding of Yorkshire, skirting the outer edge of the middle oolite, on the north of which it attains a breadth of 15 miles, and stretches across, with little interruption, from near Thirsk to the north sea. A small patch of it appears farther north, on the south-eastern coast of Sutherland, and on the east and south of the Isle of Sky.

SOIL.—It will be understood from what has been already stated in reference to other formations, that one which contains so many different rocks, as this does, must also present many diversities of soil. Where the upper beds come to the surface, the clay-partings give the character to the soil—forming a calcareous clay, which, when dry or drained, is of good quality. In other places it forms a close adhesive clay, which is naturally almost sterile. The Bath oolite weathers and crumbles readily. The soil upon it is thin, loose, and dry. The rock is full of vertical fissures, which carry off the water and drain its surface. When free from fragments of the rock, the soil is often close and impervious, and, though of a brown colour, deep, and apparently of good quality, it is really worthless, or, as the farmers call it, *dead and sleepy*. Most of this land, however, is in arable cultivation. The heavy soils, which rest on the clay containing Fuller's earth, are chiefly in pasture.

The inferior oolite varies much in its character, containing, in some places, much lime-stone, while in others, as in Yorkshire, it forms a thick mass of sand-stones and clays, with occasional thin beds of coal. In Gloucester, Oxford, Northampton, and Rutland, these lower beds form a tract of land about 12 miles in width. The soil is generally soft, sandy, micaceous, of a brown colour, and of a good fertile quality. It is deep, contains many fragments of the subjacent rock, is porous, and easily worked. Where the sand-stones prevail, it is of inferior quality. In these counties it is principally enclosed, and in arable culture, the sides of the oolitic hills and the clayey portions being in pasture. In Yorkshire, much of the unproductive moor land of the North Riding rests upon this formation. Nearly all the arable land in the county of Sutherland rests on the narrow stripe of the lower oolite rocks which occurs on its south-east coast. The debris of these rocks has formed a loamy soil, which, when well lined, produces heavy crops of turnips.

11°. *Lias.* 500 *to* 1000 *ft.* This great deposit consists chiefly of an accumulation of beds of blue clay, more or less indurated—interrupted in various places by beds of marl, and of blue, more or less earthy, lime-stones, which especially abound in the lower part of the series. The whole is full of shells, and of the remains of large extinct animals.

EXTENT.—Wherever the lower oolites are to be traced in England, the lias is seen coming up to the surface on its northern or western edge, pursuing an exceedingly tortuous north-eastern course, throwing out in its course many arms (outliers), and varying in breadth from 2 to 6 or 10 miles. It may be traced from the mouth of the Tees, in Yorkshire, to Lyme Regis, in Dorset, the continuity being broken only by the coal field of Somerset. In Scotland and Ireland no traces of this formation have yet been detected.

SOIL.—Throughout the whole of this formation the soil is a blue clay, more or less sandy, calcareous, and tenacious. Where the lime or sand prevails the soil is more open, and becomes a loam; where they are less abundant, it is often a cold, blue, unproductive, wet clay. This latter, indeed, may be given as the natural character of the entire formation. Where it rests upon a gravelly or open subsoil, or contains a large quantity of vegetable matter—it may be cultivated to advantage, and it is found especially to produce good herbage. In all situations, it is an expensive soil to work, and hence by far the greater portion of it is in old pasture. The celebrated dairy districts of Somerset, Gloucester, Warwick, and Leicester—rest for the most part on the lias, as does also much of the best grazing and pasture land in Nottingham and Yorkshire. Through the long lapse of time an artificial soil has been produced on the undisturbed surface of these clay districts which is peculiarly propitious to the growth of grass. With skilful drainage and judicious culture, it is capable of producing heavy crops of wheat.

C.—New Red Sand-stone System.

12°. *Upper and Lower Red Sand-stones.* } 500 *ft.* The upper and lower red sand-stones consist of alternate layers of sand, sand-stones, and marls sometimes colourless, but generally of a red colour—sprinkled in the upper series with frequent green spots. The lower beds are sometimes full of rolled pebbles. Few of the sand-stones of this formation are sufficiently hard to form building stones—many of the layers consist of loose friable sand, and the marls universally decay and crumble to a fine red powder under the influence of the weather.

Extent.—The new red sand-stone extends over a larger portion of the surface of England than any other formation. It commences at Torbay, in the south of Devon, runs north-east into Somersetshire; from Bristol ascends both sides of the Severn, accompanies it into the vale of Gloucester, stretches along the base of the Malvern hills, and north of the city of Worcester expands into a gently undulating plain, nearly 80 miles in width at its broadest part, comprehending nearly the whole of the counties of Warwick and Stafford and the greater part of that of Leicester. From this central plain it parts into two divisions. One of these runs west over the whole of Cheshire—(in which county it contains salt springs and mines of rock salt)—the western part of Flint, and on the south-west surrounds the county of Lancashire. It is there interrupted by the rising of the older rocks in Westmoreland, but re-appears in the eastern corner of this county, runs north-west through Cumberland, forming the plain of Carlisle—and thence round and across the Solway Frith till it finally disappears about 20 miles north of Dumfries. The other arm, proceeding from the towns of Derby and Nottingham, runs due north through Nottingham and the centre of Yorkshire, skirting the outer edge of the lias, and finally disappears in the county of Durham to the north of the river Tees. The southern portion of this arm has a width of 20 to 30 miles, until it reaches the neighbourhood of Knaresborough, where it suddenly contracts to 6 or 8, and does not again expand to more than 10 or 12 miles.

North of Dumfries-shire these rocks are not known to occur in our island. In the north-east of Ireland they form a stripe of land a few miles in width, running from Lough Foyle to Lough Neagh, and thence, with slight interruptions, to the south of Belfast.

Soil.—These rocks, by their decay, almost always produce a deep red soil. Where the red clay and marl predominate, this soil is a red clay or clayey loam of the richest quality, capable of producing almost every crop, and remarkable therefore for its fertility. It is chiefly in arable culture, because of the comparative ease with which it is worked, but the meadows are rich, and produce good herbage. Where the rocks are more sandy, and contain few marly bands, the soil produced is poorer, yet generally forms a good sandy loam, suitable for turnips and barley.

In Devonshire, as in the vale of Taunton and other localities, where the lias and the red sand-stone adjoin each other, or run side by side, the difference in the fertility and general productiveness of the two tracts is very striking. On the former, as already observed, good old grass land is seen, but the arable land on the latter produces the richest and most luxuriant crops to be seen on any soil in the kingdom. In this county, and in Somerset, the only manure it seems to require is lime, on every repetition of which it is said to produce increased crops. The same remarks as to its comparative fertility, apply with more or less force to the whole of the large area occupied by this formation in our island—wherever the soil has been chiefly formed by the decomposition of the rock on which it rests. In some localities (Dumfries-shire) the *micaceous*, marly rock is dug up, and, after being crumbled by exposure to a winter's frost, is laid on with advantage as a top-dressing to grass and other lands.

In the south of Lancashire, and along its western coast, and on the shores of the Solway, in Dumfries-shire, a great breadth of this formation is covered with peat.

13°. *Magnesian Lime-stone.*

The magnesian lime-stone is generally of a yellow, sometimes of a grey, colour. In the upper part it occasionally presents itself in thin beds which crumble more readily when exposed to the air. In some places, also, it assumes a marly character, forming masses which are soft and friable; in general, however, it is in thick beds, hard and compact enough to be used for a building stone or for mending the roads. The quantity of carbonate of magnesia it contains varies from 1 to 45 per cent. It is in the north of England generally traversed by vertical fissures which render the surface dry, and make water in many places difficult to be attained.

EXTENT.—The *magnesian limestone* stretches in an almost unbroken line nearly due north from the City of Nottingham to the mouth of the river Tyne. It is in general only a few miles in width, its principal expansion being in the county of Durham, where it attains a breadth of 8 or 10 miles.

SOIL.—It forms, for the most part, a hilly country, covered by a reddish brown soil, often thin, light and poor, where it rests immediately on the native rock—producing indifferent herbage when laid down to grass, but under skilful management capable of yielding average crops of turnips and barley. In the eastern part of the County of Durham tracts of the poorest land rest upon this rock, but as this formation is for the most part covered with deep accumulations of transported materials—the quality of the soil is in very many places more dependant upon the character of this superficial covering than upon the nature of the rock beneath.

During the slow degradation of this rock, the rains gradually wash out great part of the magnesia it contains, so that it seldom happens that the soil formed from it, though resting on the parent rock, contains so much magnesia as to be necessarily hurtful to vegetation.

D.—Carboniferous System.

14°. *Coal Measures.* 300 *ft.* Consisting of alternate beds of indurated blueish-black clay (coal shale), of siliceous sand-stone generally grey in colour and containing imbedded plants, and of coal of various qualities and degrees of thickness. Beds of limestone rarely appear in this formation till we approach the lowest part of the series.

Extent.—Fortunately for the mineral resources of Great Britain, the coal measures occupy a large area in our Island. Most of the districts in which they occur are so well known as to require only to be indicated. The south Welsh coal-field occupies the south of Pembroke, nearly the whole of Glamorgan, and part of Monmouth-shire. In the north of Somerset are the coal measures of the Bristol field which stretch also across the Severn into the forest of Dean. In the middle of the central plain of the new red sand-stone, lie the coal-fields of Ashby-de-la-Zouch, of Coventry, and Dudley, and on its western borders are those of Shropshire, Denbigh, and Flint (North Wales). To the north of this plain extends on the right the Yorkshire coal-field from Nottingham to Leeds, while on the left is the small coal-field of Newcastle-under-Line, and the broader Lancashire field which crosses the country from near Liverpool to Manchester. Almost the entire eastern half of the County of Durham, and of the low country of Northumberland, is covered with these measures—but the largest area covered by these rocks is in that part of the low country of Scotland, which extends in a north-easterly direction from the west coast of Ayrshire to the eastern coast of Fife. They there form a broad band, having an average breadth of 30 miles, interrupted often by trap or green-stone rocks, yet lying immediately beneath the loose superficial matter, over the largest portion of this extensive district. They do not occur further north in our island. In Ireland they form a tract of limited extent on the northern borders of the County of Monaghan—cover a much larger area in the south-east in Kilkenny and Queen's Counties—and towards the mouth of the Shannon, spread on either bank over a large portion of the Counties of Clare, Kerry, and Limerick.

Soil.—The soil produced by the degradation of the sand-stones and shales of the coal formation is universally of inferior quality. The black shales or schists, form alone a cold, stiff, ungrateful clay. The sand-stones alone form thin, unproductive soils, or barren—almost naked—heaths. When the clay and sand are mixed a looser soil is produced, which, by heavy limeing, by draining, and by skilful culture, may be rendered moderately productive. In the west of the counties of Durham and Northumberland, and on the higher edges of most of our coal fields, there are extensive tracts of this worthless sand-stone surface, and thousands of acres of the improvable cold clays of the shale beds. These latter soils appear very unpromising, and can only be rendered remuneratively productive in skilful hands. They present one of those cases in which the active exertions of zealous agriculturists, and the efforts of the friends of agriculture, might be expended with the promise of much benefit to the country.

15°. *Millstone Grit.* 600 *ft.* This formation consists in some localities of an entire mass of coarse sand-stone, of great thickness—in others of alternations of sand-stones and shales, resembling those of the coal-measures—while in others, again, lime-stones, more or less siliceous, are interposed among the sand-stones and shales.

Extent.—A large portion of Devonshire is covered with these rocks—they form also the high land which skirts to the north and west the coal-measures of Yorkshire, Lancashire, and Durham, and over which is the first ascent to the chain of mountains that run northward through these three counties. In Scotland, they have not been observed to lie immediately beneath any part of the surface. In the north of Ireland they cover a considerable area, stretching across the county of Leitrim between Sligo and Lough Erne.

Soil.—The soils resting upon, and formed from, these rocks are generally of a very inferior description. Where the sand-stones come to the surface, miles of naked rock appear; other tracts bear only heath, or, where the rains have only a partial outlet, accumulations of peat. The shale-beds, like those of the coal-measures, afford a cold, unproductive, yet not unimprovable soil—it is only where lime-stones occur among them that patches of healthy verdure are seen, and fields which are readily susceptible of profitable arable culture.

It is true, therefore, of this formation in general, that the high grounds form extensive tracts of moor-land. In the lower districts of country over which it extends, the soil generally rests not on the rocks themselves, but on superficial accumulations of transported materials, which are often of such a kind as to form a soil either productive in itself or capable of being rendered so by skilful cultivation.

16°. *Mountain Lime-stone.* 800 *ft.* In this formation, as its name implies, lime-stone is the predominating rock. It is generally hard, blue, and more or less full of organic remains. In some localities, it occurs in beds of vast thickness—(Derby and Yorkshire)—while in others—(Northumberland)—it is divided into numerous layers, with interposed sand-stones and beds of shale, and occasional thin seams of coal.

Extent.—The greater portion of the counties of Derby and Northumberland are covered by this formation, and from the latter county it stretches along the west of Durham through Yorkshire as far as Preston, in Lancashire—forming the mountains of the well known Pennine chain, which throw out spurs to the east and west, and thus present on the map an irregular outline and varying breadth of country. In Scotland these rocks cover only a small portion of the county of Berwick, immediately on the Border; but in Ireland, almost the entire central part, forming upwards of one-half of the whole Island, is occupied by the mountain lime-stone formation.

Soil.—From the slowness with which this rock decays, many parts of it are quite naked; in others, it is covered with a thin light porous soil of a brown colour, which naturally produces a short but thick and sweet herbage. Much of the mountain lime-stone country, therefore, is in natural pasture.

Where the lime-stones are mixed or interstratified with shale beds, which decay more easily, a deeper soil is found, especially in the hollows and towards the bottom of the vallies. These are often stiff and naturally cold, but when well drained and limed produce excellent crops of every kind. In Northumberland, much of the mountain lime-stone country is still in moor-land, but the excellence of border farming is gradually rescuing one improvable spot after another from the hitherto unproductive waste. In Yorkshire and Devonshire also improvements are more or less extensively in progress, though, in all these districts, there are large tracts which can never be re-claimed.

E.—OLD RED SAND-STONE OR DEVONIAN SYSTEM.

17°. *Old Red Sand-stone.* } 500 *to* 10,000 *ft.*

Old Red Conglomerate.
Corn-stone and Marls.
Tile-stone.

The upper part of this formation consists of red sand-stones and conglomerates (indurated sandy gravel), the middle of spotted, red and green, clayey marls, with irregular layers of hard, often impure and siliceous lime-stones (cornstones) likewise mottled, and the lowest of thin hard beds of siliceous sand-stones, sometimes calcareous, mottled, and splitting readily into thin flags (tile-stones).

Extent.—Though occasionally of vast thickness, the old red sand-stone does not occupy a *very* extensive area in our Island. In the south of Pembroke it forms a tract of land on either side of the coal-field—surrounds on the north and east the coal-field of Glamorgan, and immediately north of this county covers a large area comprehending the greater portion of Brecknock and Hereford, and part of Monmouth. A small patch occurs in the Isle of Anglesey, and in the north-eastern corner of Westmorland—but it does not again present itself till we reach the western flank of the Cheviot Hills. It there appears on either side of the Tweed, and extends over a portion of Berwick and Roxburgh to the base of the Lammermuirs. On the north of the same hills it again presents itself, and stretching to the south-west, forms a considerable tract of country in the counties of Haddington and Lanark. On the north of the great Scottish coal-field it forms a broad band, which runs completely across the island in a south-western direction along the foot of the Grampians, from Stonehaven to the Firth of Clyde, is to be discovered in the Island of Arran, and at the Mull of Cantire. and—along the prolongation of the same line—at various places on the northern flank of the great mountain lime-stone formation of Ireland, and especially in the counties of Tyrone, Fermanagh, and Monaghan. In the north of Scotland, it lines either shore of the Moray Firth, skirts the coast towards Caithness, where it covers nearly the whole county, and still further north, forms the entire surface of the Shetland Islands. Along the north-western coast, it also appears in detached patches till we reach the southern extremity of the Isle of Sky.

In Ireland, it occurs also on the extreme southern edge of the mountain lime-stone, in Waterford and the neighbouring counties—and in the middle of this formation on the upper waters of the Shannon, in the south of Mayo, and round the base of the slate mountains of Tipperary.

Soil.—The soil on the old red sand-stone admits of very nearly the same variations as on the new red sand-stone formation. Where it is formed, as in parts of Pembroke, from the upper sand-stones and conglomerates, it is either worthless or it produces a poor hungry soil, "which eats all the manure, and drinks all the water." These upper rocks are sometimes so siliceous as to be almost destitute both of lime and clay—in such cases, the soils they form are almost valueless.

The marly beds and lime-stones of the second division, yield warm and rich soils—such as the mellow lands of Herefordshire, and the best in Brecknock and Pembroke shires. The soil in every district varies according as the partings of marl are more or less numerous. These easily crumble, and where they abound form a rich stiff wheat soil—like that of East Lothian and parts of Berwickshire;—where they are less frequent the soil is lighter and produces excellent turnips and barley. Where the subsoil is porous, this land is peculiarly favourable to the growth of fruit trees.* The apple and the pear are largely grown in Hereford and the neighbouring counties, long celebrated for the cider and perry they produce.

The tile-stones reach the surface only on the northern and western edges of this formation in England. In Ayrshire, in Lanarkshire, in Ross-shire, and in Caithness, larger tracts of lánd rest on these lower beds. In all these districts rich corn lands are produced from the rocks of the middle series. The fertility of Strathmore in Perthshire, and of other vallies upon this formation, is well known—Easter Ross and Murray have been called the granary of Scotland, and even in Caithness rich corn-bearing (oat) lands are not unfrequent. Yet in the immediate neighbourhood of these rich lands, tracts of tile-stone country occur, which are either covered with useless bog (Ayrshire and Lanarkshire), or with a thin covering of soil which is almost incapable of profitable culture. In this latter condition is the moor of Beauly on the Cromarthy Firth, an area of 50 square miles, which till within a few years lay as an unclaimed common—and in the county of Caithness still more extensive tracts.

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* The most loamy of these red soils of Hereford afford the finest crops of wheat and hops, and bear the most prolific apple and pear trees, whilst the whole region (eminently in the heavier clayey tracts) is renowned for the production of the sturdiest oaks, which so abound as to be styled the "weeds of Herefordshire." Thus, though this region contains no mines, the composition of its rocks is directly productive of its great agricultural wealth.—*Murchison*, Silurian System, I., p. 193.

In South Devon and part of Cornwall a very fertile district rests also on the middle series of these rocks. Instead of red sand-stones, however, the country there consists of green slates, more or less siliceous, of sand-stones and of lime-stones, which by their decay have formed a very productive soil. These rocks in the above counties abound in fossil remains, and it is chiefly for this reason that the term *Devonian* has been applied to the rocks of the old red sand-stone formation.

III. **Primary Strata.**—In these rocks slates abound, and lime-stones are more rare. Organic remains are also less frequently met with than in the superior rocks. These remains belong all to extinct species, the greater part to extinct genera and families, and are frequently so wholly unlike to existing races that it is often difficult to trace any resemblance between the animals which now live and those which appear to have inhabited the waters of those ancient periods.

F.—SILURIAN SYSTEM.

18°. *Upper Silurian.* 3800 *ft.*

1°. LUDLOW FORMATION.	
a Upper Ludlow	2000
b Aymestry Lime-stone	
c Lower Ludlow	
2°. WENLOCK FORMATION.	
a Lime-stone	1800
b Shale	

The upper Ludlow rocks consist of sand-stones more or less calcareous and argillaceous. These rest upon hard, somewhat crystalline, earthy lime-stones (Aymestry lime-stones.) The lower Ludlow rocks are masses of shale more free from lime and sand than the upper beds, and from the mode in which they decay into *mud* are locally known by the name of "mud-stones."

The Wenlock or Dudley formation consists in the upper part of a great thickness of lime-stone beds often argillaceous, and abounding in the remains of marine animals; and in the lower part of thick beds of a dull clayey shale—in its want of cohesion, and in its mode of decay, very much resembling the *mud-stones* of Ludlow.

Extent—. The principal seat of these rocks in our Island is in the eastern counties of Wales, where they lie immediately beneath the surface over the eastern half of Radnor, and the north of Montgomery.

Soil.—The prevailing character of the soils upon these formations is derived from the shales and mud-stones—and from the earthy layers of the sand-stones and lime-stones which decay more readily than the purer masses of these rocks. The traveller is immediately struck in passing from the rich red marls and clays of the old red sand-stone in Hereford, on to the dark, almost black, soils of the upper and lower Ludlow rocks in Radnor, not merely by the change of colour, but by their obviously diminished value and productiveness. The upper Ludlow is crossed by many vertical cracks and fissures, and thus, though clayey, the soil which rests upon it is generally dry, and susceptible of cultivation.

Not so the *muddy* soils of the lower Ludlow and Wenlock rocks. They are generally more or less impervious to water, and being subject to the drainage of the upper beds, form cold and comparatively unmanageable tracts. It is only where the intermediate lime-stones (Aymestry and Wenlock lime-stones) come to the surface and mingle their debris with those of the upper and lower rocks, that the stiff clays become capable of bearing excellent crops of wheat. This fact, however, indicates the method by which the whole of these cold wet clays might be greatly improved. By perfect artificial drainage and copious limeing, the unproductive soils of the lower Ludlow and of the Wenlock shales might be converted into wheat lands more or less rich and fertile. It unfortunately happens, however, that in those districts of North and South Wales, where the dark grey or black "*rotchy*" land of the mud-stones prevails, lime is often so scarce or has to be brought from so great a distance, as to render this means of improvement almost unattainable.

19°. *Lower Silurian.* 3700 *ft.*

Caradoc Sand-stones	2500
Llandeilo Flags	1200

The Caradoc beds consist of thick layers of sand-stone of various colours, resting upon, and covered by, and occasionally interstratified with thin beds of impure lime-stone. The Llandeilo flags which lie beneath them consist of thin calcareous strata, in some localities alternating with sand-stones and shales.

Extent.—These rocks form patches of land in Shropshire and the north of Montgomery—and skirt the southern and eastern edge of Caermarthen. None of the Silurian rocks have yet been found to extend over any large portion of either Scotland or Ireland.

Soil.—The Caradoc sand-stone, when free from lime, produces only a naked surface or a barren heath. The Llandeilo flags form a fertile and arable soil, as may be seen in the south of Caermarthen, where they are best developed, and especially on the banks of the Towey, which for many miles before it reaches the town of Caermarthen runs over this formation.

In this formation, as in every other we have yet studied, the soil changes immediately on the appearance of a new rock at the surface. The soil of the Wenlock shale is sometimes more sandy as it approaches the Caradoc beds, and on favourable slopes forms good arable land and sustains luxuriant woods, but where the Caradoc sand-stones reach the surface, a wild heath or poor wood-land stretches over the country, until passing over their edges we reach the lime-containing soils of the Llandeilo flags, when fertile arable lands and lofty trees again appear.*

G.—CAMBRIAN SYSTEM.

20°. *Upper & Lower Cambrian Rocks.* } These rocks, which are many thousand yards in thickness, consist chiefly of thin slates often hard and cleaving readily, like roofing slates, occasionally intermingled with sandy and thin lime-stone beds. They contain few organic remains.

EXTENT.—These rocks cover the whole of Cornwall, part of North and South Devon, the western half of Wales, the entire centre of the Isle of Man, and a large part of Westmorland and South Cumberland. In Scotland, they form a band between 30 and 40 miles in width, which crosses the Island from the Mull of Galloway to St. Abbs Head. They form also a narrow stripe of land, which recrosses the Island along the upper edge of the old red sand-stone from Stonehaven to the Isle of Bute, and, further north, spread over a considerable portion of Banffshire. In the south-west of Ireland they attain a great breadth, are narrower at Waterford, but form a broad band along the granite mountains from that city to Dublin. They extend over a large portion of the counties of Louth, Cavan, Monaghan, Armagh, and Down,—form a narrow stripe also along the coast of Antrim as far north as the Giant's Causeway,—and, in the interior of Ireland, re-appear in the mountainous district of Tipperary.

SOIL.—The predominance of slaty rocks in this formation imparts to the soils of the entire surface over which they extend one common clayey character. They generally form elevated tracts of country, as in Wales, Cumberland, Scotland, and Ireland, where the rigours of the climate combine with the frequent thinness and poverty of the soil to condemn extensive districts to worthless heath or to widely extended bogs. Yet the slate rocks themselves, especially when they happen to be calcareous, are capable of producing fertile soils. Such are found in the valleys, on the hill sides, and by the margins of the lakes that are often met with in the slate districts. More extensive stripes or bands of such productive land occur also at lower levels, as in the north of Devon, and in the south of Cornwall. In the latter county, the soils on the *hornblende slate* (which lies near the bottom of the slate series) are extremely fertile, exhibiting a striking contrast with those which are formed from the neighbouring Serpentine rocks, that extend over a large area immediately north of the Lizard (see p. 386.)

Where the clay-slate soils occur, therefore, however cold and stiff they may be, a favourable climate, drainage, if necessary, and lime, either naturally present, or artificially added, appear to be the first requisites to insure fertility.

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* Such a passage from one formation to another is exhibited in the diagrams inserted in pages 349 and 350.

The mode in which these rocks lie, or the degree of inclination which the beds exhibit, exercises an important influence upon the agricultural character of the soils that rest upon them. In the diagram inserted in p. 350, the rocks (A) represent the highly inclined, often nearly vertical position, in which the slate rocks are most frequently found. The soil formed from them must, therefore, rest on the thin edges of the beds. Thus it happens in many localities that the rains carry down the soluble parts of the soil and of the manure within the partings of the slates —and hence the lands are hungry and unprofitable to work.

On the slopes of the clay slate hills of the Cambrian and Silurian systems, flourish the vineyards of the middle Rhine, the Moselle, and the Ahr.

H.—MICA-SLATE AND GNEISS SYSTEMS.

21°. *Mica-Slate,* } *Gneiss Rock.* }

The upper of these formations consists of thin undulating layers of rock, consisting chiefly of quartz and mica, alternating occasionally with green (chlorite) slates, common clay-slates, quartz rock and hard crystalline limestones. The gneiss is a hard and solid rock of a similar nature, consisting of many thin layers distinctly visible, but firmly cemented, and as it were half-melted together.

EXTENT.—Two-thirds of Scotland, comprehending nearly the whole country north and west of the Grampians, consist of these rocks. In England there is only a small patch of mica slate about Bolt Head and Start Point in South Devon, and a somewhat larger in Anglesey; but in Ireland, nearly the whole of the counties of Donegal and Londonderry on the north, and a large portion of Mayo, Connaught, and Galway, on the west, are covered by rocks belonging to the mica slate system.

SOILS.—These rocks are, in general, harder still than those of the Cambrian system, and still more impervious to water, when not highly inclined. They crumble slowly, therefore, and imperfectly, and hence are covered with thin soils, on which, where good natural drainage exists, a coarse herbage springs, and from which an occasional crop of corn may be reaped—but on which, where the water becomes stagnant, extensive heaths and bogs prevail. That they contain, when perfectly decomposed and mellowed, the materials of a fertile soil, is shown by the richness of many little patches of land, that occur in the sheltered valleys of the Highlands of Scotland, and by the margins of its many lakes. In general, however, the mica-slate and gneiss country is so elevated that not only does an ungenial climate assist its natural unproductiveness, but the frequent rains and rapid flowing rivers bear down to the bottoms of the vallies or forward to the sea, much of the finer matter produced by the decay of the rocks,—leaving only a poor, thin, sandy soil behind.

On these hard slate and gneiss rocks extensive pine forests in Sweden and Norway have long lived and died. In these countries it is customary in many places to burn down the wood, to strew the ashes over the thin soil, to harrow in the seed—to reap thus one or two harvests of rye, and to abandon it again to nature. A grove of beech first springs up, which is supplanted by an after-growth of pine, and finally disappears.

Such is a general description of the nature and order of succession of the stratified rocks, as they occur in Great Britain and Ireland—of the relative areas over which they severally appear at the surface—and of the kind of soils which they produce by their natural decay. The consideration of the facts above stated,* shews how very much the fertility of each district is dependant upon its geological structure—how much a previous knowledge of that structure is fitted to enlighten us in regard to the nature of the soils to be expected in any district—to explain anomalies also in regard to the unlike agricultural capabilities of soils apparently similar—to indicate to the purchaser where good or better lands are to be expected, and to the improver, whether the means of ameliorating his soil by limeing, by marling, or by other judicious admixture, are likely to be within his reach, and in what direction they are to be sought for. There still remain some important branches of this subject to which, at the risk of fatiguing you, it will be my duty briefly to draw your attention in the following lecture.

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* For much of the practical information contained in this section, I have to express my obligations to the following works:—For the extreme southern counties, to De La Beche's *Geological Report on Cornwall and Devon;* and to a paper by Sir Charles Lemon, Bart., on the *Agricultural Produce of Cornwall;*—for Wales and the Border counties, to Murchison's *Silurian System;*—for the Midland counties of England, to Morton *on Soils*, a work I have in a previous note recommended to the attention of the reader; for Yorkshire, to a paper by Sir John Johnston, Bart., in the *Journal of the Royal Agricultural Society;*—and for the Old Red Sand-stone of the north of Scotland, to the very interesting little work of Mr. Miller on *The Old Red Sand-stone*. The reader would read the above Section with much greater profit if he were previously to possess himself of Phillips' *Outline Map of the Geology of the British Islands.*

LECTURE XII.

Composition of the granitic rocks and of their constituent minerals—Cause and mode of their degradation—Soils derived from them—Superficial accumulations—their influence upon the character of the soils—Organic constituents, ultimate chemical constitution, and physical properties of soils.

It has been stated in the preceding Lecture (§ 6, p. 349), that the rocks which present themselves at the surface of the earth are of two kinds, distinguished by the terms *stratified* and *unstratified*. The former crumble away, in general, more rapidly than the latter, and form a variety of soils of which the agricultural characters and capabilities have been shortly explained. The unstratified or crystalline rocks form soils of so peculiar a character and possessing agricultural capabilities in general so different from those of the stratified rocks which occur in the same neighbourhood; and they, besides, cover so large and hitherto so unfruitful an area in our island, as to entitle them to a separate and somewhat detailed consideration.

§ 1.—*Composition of the Granitic Rocks.*

The name of *Granite* is given by mineralogists to a rock consisting of a mixture more or less intimate of three simple minerals—*Quartz*, *Mica*, and *Felspar*. When Mica is wanting, and *Hornblende* occurs in its stead, the rock is distinguished by the name of *Syenite*. This mineralogical distinction is often neglected by the geologist, who describes large tracts of country as covered by granitic rocks, though there may be many hills or mountains of syenite. In a geological sense, the distinction is often of little consequence; in relation to agriculture, however, the distinction between a granite and a syenite is of considerable importance.

The minerals of which these rocks consist are mixed together in very variable proportions. Sometimes the quartz predominates, so as to constitute two-thirds or three-fourths of the whole rock, sometimes both mica and quartz are present in such small quantity as to form what is then called a felspar rock. The mica rarely exceeds one-sixth of the whole, while the hornblende of the syenites sometimes forms nearly one-half of the entire rock. These differences also are often overlooked by the geologist—though they necessarily produce important differences in the composition and agricultural characters of the soils derived from the crystalline rocks.

A few other minerals occur occasionally among the granitic rocks, in sufficient quantity to affect the composition of the soils to which they give rise. Among these, the different varieties of tourmaline are in many places abundant. Thus the *schorl* rock of Cornwall, consists of quartz and schorl (a variety of tourmaline), while crystals of schorl are so frequently found in the granites of Devon, Cornwall, and the Scilly Isles, as to be considered characteristic of a very large portion of them (Dr. Boase).

These rocks decay with very different degrees of rapidity—according to the proportions in which the several minerals are present in them, and to the peculiar state of hardness or aggregation in which they happen to occur. Both the mode of their decay, however, and the circumstances under which it takes place, as well as the character and composition of the soils formed from them, are materially dependant upon the composition of the several minerals of which the rocks consist. This composition, therefore, it will be necessary to exhibit.

1°. *Quartz* has already been described (p. 303), as a variety of silica—the substance of flints, and of siliceous sands and sand-stones. In granite, it often occurs in the form of rock crystal, but it is more frequently disseminated in small particles throughout the rocky mass. It is hard enough to scratch glass.

2°. *Felspar* is generally colourless, but is not unfrequently reddish or flesh-coloured. On the colour of the felspar they contain, that of the granites most frequently depends. Several varieties of this mineral are known to collectors. Besides the common felspar, however, it is only necessary to specify *Albite*, which, in appearance, closely resembles felspar, often takes its place in granite rocks, and in chemical constitution differs from it only in containing soda, while the common felspar contains potash. These two minerals are readily distinguished from quartz by their inferior hardness. They do not scratch glass, and, in general, may easily be scratched by the point of a knife.

They consist respectively of—

	Felspar.	Albite.
Silica	65·21	69·09
Alumina . . .	18·13	19·22
Potash . . .	16·66	—
Soda	—	11·69
	100·00	100·00

It is to be observed, however, that these minerals do not generally occur in nature in a perfectly pure state—for though they do not essentially contain either lime, magnesia, or oxide of iron, they are seldom found without a small admixture of one or more of these substances. It is also found that while pure felspar contains only potash, and pure albite only soda, abundance of a kind of intermediate mineral occurs which contains both potash and soda. Such is the case with the felspars of the Siebengebirge, on the right bank of the Rhine (Berthier), and with those contained in the lavas of Vesuvius and the adjacent parts of Italy (Abich).

In these two minerals the silica is combined with the potash, soda, and alumina, forming certain compounds already described under the name of *silicates* (p. 305).

Felspar consists of a silicate of alumina combined with a *silicate of potash*. *Albite* of the same silicate of alumina combined with a *silicate of soda*.

3°. *Mica* generally occurs disseminated through the granite in small shining scales or plates, which, when extracted from the rock, split readily into numerous inconceivably thin layers. It sometimes occurs also in large masses, and is of various colours—white, grey, brown, green, and black. It is soft and readily cut with a knife. The thin shining particles that occur in many sand-stones, and especially between the partings of the beds, and give them what is called a *micaceous* character, are only more or less weathered portions of this mineral.

Mica also consists of silicates, though its constitution is not always so simple as that of felspar. In some varieties magnesia is present, whilst in others it is almost wholly wanting, as is shewn by the following composition of two specimens from different localities.

	Potash. Mica.		Magnesian. Mica.
Silica	46·10		40·00
Alumina.	31·60		12·67
Prot-Oxide of Iron .	8·65		19·03
Magnesia	—		15·70
Potash	8·39		5·61
Oxide of Manganese .	1·40		0·63
Fluoric Acid . . .	1·12		2·10
Water	1·00	Titanic Acid	1·63
	98·26		97·37

If we neglect the three last substances which are present only in small quantities, and recollect that the silica is *in combination* with all the other substances which stand beneath it, we see that these varieties of mica consist of a silicate of alumina, combined in the one with *silicate of iron* and *silicate of potash*, and in the other with *silicate of iron* and *silicate of magnesia*.

4°. *Hornblende* occurs of various colours, but that which forms a constituent of the syenites and of the basalts is of a dark green or brownish black colour, is often in regular crystals, and is readily distinguished from quartz and felspar by its colour, and from black mica by not splitting into thin layers, when heated in the flame of a candle. It consists of silicates of alumina, lime, magnesia, and oxide of iron, or per cent. of—

	Basaltic Hornblende.	Syenitic Hornblende.
Silica	42·24	45·69
Alumina	13·92	12·18
Lime	12·24	13·83
Magnesia	13·74	18·79
Prot-Oxide of Iron .	14·59	7·32
Oxide of Manganese	0·33	0·22
Fluoric Acid . . .	—	1·50
	97·06	99·53

A comparison of these two analyses shows that the proportions of magnesia and oxide of iron sometimes vary considerably, yet that the hornblendes still maintain the same general composition. They are remarkably distinguished from felspar *by the total absence of potash and soda, and by containing a large proportion of lime and magnesia.* From the potash-mica they are distinguished by the same chemical differences, and from the magnesian mica by containing lime to the amount of ⅛th part of their whole weight. Such differences must materially affect the constitution and agricultural capabilities of the soils formed from these several minerals, and they show the correctness of what I have previously stated to you—that mineralogical differences in rocks which may be neglected by the geologist, may be of great importance in explaining the appearances that present themselves to the philosophical agriculturist.

4°. *Schorl* usually occurs in the form of long black needles or prisms disseminated through the granitic rock, and generally (in Cornwall) at the outskirts of the granite, where it comes into contact with the slate rocks that surround it (De La Beche). It consists of a silicate of alumina in combination with silicates of iron and of soda or magnesia. Two varieties gave by analysis—

	Schorl from Devonshire.	Tourmaline from Sweden.
Silica, ...	35·20	37·65
Alumina, ...	35·50	33·46
Magnetic Oxide of Iron,	17·86	9·38
Magnesia, ...	0·70	10·98
Boracic Acid, . . .	4·11	3·83
Soda, ...	2·09	Soda & Potash, 2·53
Lime, ...	0·55	0·25
Oxide of Manganese,	0·43	—
	96·44	98·08

This mineral, according to these analyses, is characterised by containing from ⅕ to ⅒ of its weight of magnetic oxide of iron,* and sometimes ⅒ of magnesia. The presence of Boracic acid* is also a remarkable character of this mineral, but as neither the presence of this substance in any soil, nor its effect upon vegetation, have hitherto been observed, we can form no opinion in regard to its importance in an agricultural point of view.

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* This oxide is composed of the *first* and *second* oxides of iron described in p. 311.

§ 2. *Of the degradation of the Granitic rocks, and of the soils formed from them.*

The granites, in general, are hard and durable rocks, and but little affected by the weather. The quartz they contain is scarcely acted upon at all by atmospheric agents, and in very many cases the felspar, mica, and hornblende yield with extreme slowness to their degrading power. It is chiefly to the *chemical decomposition* of the felspar that the wearing away of granite rocks is due, and the formation of a soil from their crumbling substance.

It has been stated that the felspars consist of a silicate of alumina in combination with silicates of potash or of soda. Now these latter silicates are slowly decomposed by the carbonic acid of the air (see p. 305), which combines with the potash and soda, and forms *carbonates* of these alcalies. These carbonates are very soluble in water, and are, therefore, washed away by the first shower of rain that falls. The insoluble *silica* and the silicate of alumina are either left behind or are more slowly carried away by the rains in the form of a fine powder (a fine porcelain clay), and deposited in the valleys or borne into the rivers and lakes,—while the particles of quartz and mica, having lost their cement of felspar, fall asunder, and form a more or less siliceous sand.

Granite soils, therefore, on all *hanging grounds*,—on the sides and slopes of hills, that is—are poor and sandy, rarely containing a sufficient admixture of clay to enable them to support crops of corn—while at the bottoms of the hills, whether on flat or hollow grounds, they are composed, in great measure, of the fine clay which has resulted from the gradual decomposition of the felspar.

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* Boracic acid occurs in combination with soda in the common *borax* of the shops. It combines with soda, potash, lime, &c., and forms *borates*. In the schorl it probably exists in such a state of combination.

This clay consists chiefly of the silicate of alumina contained naturally in the felspar—it differs little, in short, from that which has already been described (p. 341), under the name of pure or pipe clay, which is too stiff and intractable to be readily converted into a prolific soil.

It will readily be understood how such soils—decomposed felspar soils—must generally contain a considerable quantity of potash from the presence of minute particles of silicate of potash still undecomposed; and it will be as readily seen that they can contain little or no lime, since neither in felspar nor in mica has more than a trace of this earth been hitherto met with.

We have seen, however, that hornblende contains from $\frac{1}{7}$th to $\frac{1}{8}$th of its weight of lime, and as the same carbonic acid of the atmosphere which decomposes the felspar, decomposes the silicates of the hornblende also, it is clear that soils which are derived from the degradation of syenitic rocks, especially if the proportion of hornblende present in them be large, will contain lime as well as clay and silica. Thus consisting of a greater number of the elements of a fertile soil, they will be more easily rendered fruitful also—must naturally be more fruitful—than those which are formed from the granites, correctly so called. It is to the presence of this lime that the superior fertility of the soils derived from the hornblende slates of Cornwall, already adverted to (p. 371), is mainly to be ascribed.

Schorl, as above stated, contains much oxide of iron, and sometimes five or six per cent. of magnesia. It decomposes slowly, will give the soil a red colour, and though it contain only a trace of lime, yet the admixture of its constituents with those of the felspar *may possibly* ameliorate the quality of a soil formed from the decay of the felspar alone.

It thus appears that a knowledge of the constitution of the minerals of which the granites are composed, and of the proportions in which these minerals are mixed together in any locality, clearly indicates what the nature of the soils formed from them *must* be—an indication which perfectly accords with observation. The same knowledge, also, showing that such soils never have contained, and never can, naturally, include more than a trace of lime, will satisfy the improver, who believes the presence of lime to be almost necessary in a fertile soil, as to the first step to be taken in endeavouring to rescue a granitic soil from a state of nature—will explain to him the reason why the use of lime and of shell sand on such soils, should so long have been practised with the best effects,—and will encourage him to persevere in a course of treatment which, while suggested by theory, is confirmed also by practice.

Extent of granitic rocks in Great Britain and Ireland.—In England, the only extensive tracts of granite occur in Cornwall and Devon, presenting themselves here and there in isolated patches from the Scilly Isles and the Land's End to Dartmoor in South Devon. In the latter locality, the granite rocks cover an area of about 400 square miles. Proceeding northward, various small *out-bursts** of granite appear in the Isle of Anglesey, in Westmoreland, and in Cumberland, and north of the Solway, in Kirkcudbright, it extends over 150 or 200 square miles;—but it is at the Grampian Hills that these rocks begin to be most extensively developed. With the exception, indeed, of the patches of old red sandstone already noticed, nearly the whole of Scotland, north of the Grampians—and of the western islands, excluding Sky and Mull, consists of granitic rocks.

In Ireland, a range of granite (the Wicklow) mountains runs south by west from Dublin to near New Ross—the same rock forms a considerable portion of the monntainous districts in the north-west of Donegal, and in the south of Galway—covers a less extensive area in Armagh, and presents itself in the form of an isolated patch in the county of Cavan.

Soils of the granitic rocks.—From what has been already stated in regard to the composition of granite, it is clear from theory that no generally uniform quality of soil can be expected to result from its decomposition, and this deduction is confirmed by practical observation. Where quartz is more abundant, or where the clay is washed out, the soil is poor, hungry, and unfruitful—such, generally, is its character on the more exposed slopes of the hills in the Western Isles,* and in the north of Scotland. In the hollows and levels, where natural drainage exists, stiff clay soils prevail, which are often cold and unfruitful, but are capable of amelioration where the depth of earth is sufficient, by draining and abundant limeing or marling. Where there is no natural drainage, vegetable matter accumulates, as we have seen to be the case on the surface of all impervious rocks—and bogs are formed. In the north of Scotland, and in Ireland, and in the high lands in Dartmoor (Devon), these are everywhere seen in such localities, and it is said that two-thirds of the Hebrides are covered with peat bogs more or less reclaimable.

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* This expression is in some measure theoretical, and implies—what is the generally received opinion—that the granite rocks were forced up from beneath in a fluid state, like the lavas of existing volcanoes—that they, as well as the trap rocks, are, in short, only lavas of a more ancient date (see p. 349).

In Cornwall and Devon, the granitic soils (*growan* soils as they are there called) are observed to be more productive, as the hills diminish in height. Thus Dartmoor is covered only with heath, coarse grass, and peat; while in the Scilly Isles the growan land produces good crops of wheat, potatoes, barley, and grass; and the same is observed at Moreton Hampstead, in Devon, where tolerable crops of barley are grown, and potatoes, which are highly esteemed in the Exeter market (De La Beche). No doubt the climate has something to do with these differences; but the less the elevation, and the consequent washing of the rains, the more of the clay will remain mixed with the siliceous sand; while in aid of both these causes, a small difference in the composition of its constituent minerals, often not to be detected by the eye, may materially affect the character of the granitic soils.

According to Dr. Paris, the presence of much mica deteriorates these soils; while that which is formed at the edges of the granite, when it comes in contact with the slate rocks, is of a more fertile quality. The latter remark, however, does not universally apply,—especially where the granite, as at the edges of Dartmoor, contains much schorl, (De La Beche)—and the presence of mica, in the richest soils of the red marl, would seem to imply that this mineral is fitted materially to promote the fertility of a soil in which the other earthy ingredients are properly adjusted.

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* Macdonald's *Agricultural Survey of the Hebrides*, p. 26.

The more elevated and thin granitic soils are said to be fitted for the growth of larch; the lower and deeper soils, which admit of the use of the plough, have been found to yield a three-fold return of corn by the use of lime alone.

§ 4. *Of the Trap rocks, and the soils formed from them.*

Of the trap rocks there are several varieties, of which the most important are distinguished by the names of *Green-stone*, *Basalt*, and *Serpentine*.

The Green-stones consist of a mixture more or less intimate of felspar and hornblende, or of felspar and *augite*. They are distinguished from the granites by the absence of mica and quartz, and by the presence of the hornblende or augite, often in equal, and not unfrequently in greater quantity than the felspar. In the granites, the felspar and quartz together generally form upwards of $\frac{8}{10}$ of the whole mass.

Augite is a mineral having much resemblance to hornblende, and like it occurring of various colours. In the trap rocks it is usually of a dark green approaching to black. It generally contains much lime and oxide of iron in the state of silicates. The composition of two varieties compared with that of *basaltic* hornblende is as follows:—

	Black Augite from Sweden.	Augite from the lava of Vesuvius.	Basaltic Hornblende.
Silica	53·36	50·90	42·24
Lime	22·19	22·96	12·24
Magnesia	4·99	14·43	13·74
Prot-Oxide of Iron . .	17·38	6·25	14·59
Prot-Oxide of Manganese	0·09	—	0·33
Alumina	—	5·37	13·92
	98·01	99.91	97·06

The predominance of this mineral (augite) or of hornblende in the green-stone rocks must necessarily cause a very material difference in the nature of the soils produced from their decay, compared with those which are formed from the granitic rocks in which the felspars are the predominating mineral ingredient.

2°. *Basalt* consists of a mixture, in variable proportions, of augite, magnetic oxide of iron, and *zeolite.*[*] It differs in appearance from green-stone, chiefly by the darkness of its colour, and by the minuteness of the particles of which it is composed, which, in general, cannot be distinguished by the naked eye.

Zeolite is a generic term applied to a great number of mineral species which occur in the basalts, and often intermixed with the green-stone rocks. *They differ from felspar in their greater solubility in acids, and by generally containing lime, where the latter contains potash or soda.*

It may be stated, indeed, as the most important agricultural distinction, between the granitic and the true[†] trap rocks, that the latter abound in lime, while in the former, it is often entirely absent. If in a green-stone only one-fourth of its weight consist of augite, every 20 tons of the rock may contain one ton of lime. If in a basalt the augite and zeolite amount to only two-thirds of its weight, every nine tons may contain a ton of lime. The practical farmer cannot fail to conclude that a soil formed from such rocks must possess very different agricultural capabilities from the soils we have already described as being formed from the decomposition of the granites.

3°. *Serpentine* is a greenish yellow mineral, consisting of silica in combination with magnesia and a little iron, and *occasionally* a few pounds in the hundred of lime or alumina.

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[*] "*With or without felspar.*" In addition to augite, magnetic iron, and zeolite, many basalts contain also a considerable portion of certain *varieties* of felspar, especially of one to which the name of *nepheline* has been given.

[†] *Serpentine* is not generally included among the *true* trap rocks: it is included among them here as it often is by geologists, because in many places, as at the Lizard, it occurs along with true green-stone.

The distinguishing ingredient is the magnesia, which generally approaches to 40 per cent. of the whole weight of the mineral. Rocks of serpentine are generally mixed with magnetic iron ore, and with portions of other minerals in greater or less abundance.

Extent of the trap rocks in the British Isles.—The serpentine rock occurs to any extent only in Cornwall, about the Lizard Point, where it covers an area of 50 square miles. The green-stones and basalts are only met with here and there in small patches, until we get so far north as the Cheviot Hills, which consist of these and other varieties of trap. It is in the low country of Scotland, however, intermixed with and surrounding the great coal district of that part of the island, that the greatest breadth of trap is seen. It there stretches across the island in a south-west direction, and in detached masses, from the Friths of Tay and Forth to the island of Arran, covering an area of 800 or 1000 square miles. In the prolongation of the same line it re-appears in the north-east of Ireland, and extends over the whole of the county of Antrim and a small part of Londonderry and Armagh. In the most northerly portion of this tract the well-known columnar basalt of the Giants' Causeway occurs. On the west coast of Scotland the trap rocks cover nearly the whole of the islands of Mull and of Skye—to the west of the former of which islands lies Staffa with its celebrated basaltic caves.

Soil of the trap rocks.—The soil of the serpentine rocks at the Lizard is far from fertile, retaining the water and thus forming swamps and marshes. Even where a natural drainage exists it rarely produces good grass, or average crops of corn. It is remarkable for growing a peculiar, very beautiful heath—*erica vagans*—which so strictly limits itself to the serpentine soil as distinctly to mark the boundary by which the serpentine is separated from other rocks (De La Beche). From the composition of serpentine we might be led to suppose that the comparative barrenness of the soils formed from it is due to the large quantity of magnesia which this mineral contains; and this may, in some cases, be partly the cause. It would appear, however, that these soils often contain very little magnesia, the long action of the rains and of other agents having almost entirely removed it (see p. 308), and yet they still retain their barrenness. But they contain no lime, and, therefore, after draining, the first great step to take in order to improve such soils, is to give them a good dose of lime. How this step is to be followed up will depend upon the effect which this treatment is found to produce.

The soil of the green-stones is generally fertile, and it is more so in proportion as the hornblende or augite predominates—that is, generally, in proportion to the darkness of its colour.

In Cornwall and South Devon, where scattered masses of trap occur, consisting chiefly of hornblende and felspar, they " afford the most fertile soils of any in the district when their decomposition has taken place to a sufficient depth" (De La Beche). Wherever the trap rocks (locally *dunstones*) are observed at the surface, " it is deemed a fortunate circumstance, being a certain indication of the fertility of the incumbent soils."* The superior fertility of the neighbourhood of Penzance is owing to the presence of these rocks (Dr. Paris), and where their detritus has been mixed with that of other rocks—as with the worthless granite soils—it ameliorates and improves their quality.

The same general character is exhibited by the trappean soils of other districts of the island. The height of the Cheviot Hills renders the climate in many places unfavourable to arable culture, yet they produce the sweetest pasture,† while the low country around them has been largely benefitted by admixture with their crumbling fragments. The whole of that lowland tract of Scotland, over which these rocks extend—comprehending the counties of Ayr, Renfrew, Lanark, Linlithgow, Fife, and portions of Perth, Stirling, Edinburgh, and Haddington,—exhibit the fertile or fertilizing character of the decomposing greenstone. In Cornwall it is dug up as a marl and applied to the land, and in the neighbourhood of Haddington I have seen a farming tenant (*a leaseholder*) removing twelve inches of *trap* soil from the entire surface of a field, for the purpose of spreading a layer of an inch in depth over twelve times the area in another part of his farm. There can be no doubt that this mode of improvement is within the reach of many proprietors and farmers—especially along the southern borders of Perthshire and near the more elevated parts of Ayr and Lanark.

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* Worgan's *View of the Agriculture of Cornwall*, p. 10.

† It is a singular fact observed here and there among the Cheviot Hills on the border, that where sheep are folded or pastured on hills of trap which are covered with delicate herbage, they are attacked by what is locally called the *pining ill*,—they pine away, become indolent, and are unwilling to move. The cure is to drive them to a neighbouring *sand-stone pasture*, where they become again active, and begin to thrive. The *pining* hills on each farm are well known, and the tenant has no hesitation in pointing to this and to that hill as those on which the sheep are sure to pine, if kept upon them only.

To the north of Ireland, and to the Western Islands, the above remarks, with slight modifications, arising from local causes, will also apply. For example, where the surface is flat, and the rock impervious, water will collect and heaths and bogs will be produced, which only draining can remove. They apply also to other countries where trap rocks abound —the only fertile tracts of Abyssinia, for instance, being found in vallies and on mountain slopes, where the soil is composed of the detritus of trappean rocks (Dr. Rüppell).

Yet there are exceptions to this general rule.

Where the felspar is largely predominant, the soil formed from the rock will partake more or less of the cold and barren character of the stiffer granitic soils. Such appears to be the case with some of the traps which occur in the border counties of England and Wales (Murchison).

In the Isle of Skye, again, a local peculiarity of a different kind obtains, the effect of which upon the soil is also to render it poor and unproductive. In that island the singularly beautiful ridge of the Cuchullen Hills consists of a variety of trap in which the augite so far predominates as to form nearly the whole of the mountain masses. But the augite in this case is a variety to which the name of *hypersthene* has been given, and which contains much magnesia and oxide of iron, but *scarcely a trace of either lime or alumina.* The rock is very hard, and decays with extreme slowness; yet however rapid its decay might be, it could never produce a fertile soil. We have seen that the serpentine and granite soils are essentially deficient in lime, but a hypersthene soil is in want both of lime and of clay. It would be still more difficult, therefore, to render the latter productive—even supposing, as in the case of the serpentine soils, that the magnesia of the hypersthene* were mostly washed away by the rains.

Thus we perceive how exactly the study of the composition of the different varieties of the trap rocks explains the observed differences in the quality of the soils derived from them. When the minerals they contain abound in lime, the soils they yield are fertile—when those minerals predominate in which lime is wanting, the soils are inferior, sometimes scarcely capable of cultivation. Again, the granites abound in potash; but except in the syenites they rarely contain lime, and their soils are generally poor. Let them be mixed with the trap soils, and they are enriched. This would seem fairly and clearly to imply that the fertility of the one is mainly due to the presence of lime, and the barrenness of the other to the absence of this earth.

On this subject I will only further add, that the more modern volcanic lavas which overspread Italy, Sicily, parts of France, Spain, and Germany, are closely related to the trap rocks in their general composition—and the fertility which overspreads thousands of square miles of decomposed lava streams and ejections of volcanic ashes in Italy and Sicily, is too well known to require any detailed description.

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* The hypersthene of Skye has been found to consist of—

Silica, ...	51·35	Prot-oxide of Iron, . .	33·92
Lime, ...	1·84	Water, ...	0.50
Magnesia, . . .	11·09		
			98·70

The composition probably varies in different parts of the rock, some containing more magnesia and less iron than is here represented.

§ 5. *Of superficial accumulations of foreign materials, and of the means by which they have been transported.*

Abundant proof, I think, has now been advanced that a close relation *generally* exists between the soil and the rocks on which it rests, and that the geological structure of a country, as well as the chemical constitution of the minerals of which its several rocky masses consist, have a primary and fundamental influence upon the agricultural capabilities of its surface.

And yet I should be leading you into a serious error, were I to permit you to suppose that this intimate and direct relation is always to be observed—that in whatever district you may happen to be, you will find the soil taking its general character from the subjacent rocks—and that where the same rocks occur, similar soils are always to be expected. On the contrary, in very many localities the soil is totally different from that which would be produced by the degradation or decomposition of the rocks on which it rests. To infer, therefore, or to predict, that on a given spot, where, according to the geological map, red sand-stone for example prevails, a marly or other red sand-stone soil will necessarily be found—or that where the coal measures are observed, poor, ungrateful land must exist—would be to form or to state opinions which a visit to the several localities would in many instances show to be completely erroneous—and which would bring undeserved discredit upon geological science.

In such cases as these geology is not at fault. New conditions only have supervened which render the natural relation between soils and rocks in those places less simple, and consequently more obscure. Yet a further study of geological phenomena removes the obscurity—shows to what cause it is owing that in many districts the soil is such as could never have been formed from the subjacent rocks—again places the enlightened agriculturist in a condition to pronounce generally from what rocks his soils have been derived—generally also what their agricultural capabilities are likely to be, and by what mode of treatment those capabilities may be most fully developed.

Of the surface of Great Britain and Ireland it may indeed be truly said, that it exhibits extensive tracts in which the character of the soil is directly influenced by, and may be inferred from, the character and composition of the subjacent rock. To these districts the rules and observations contained in the preceding sections directly and clearly apply. But other extensive tracts also occur in which the character of the soil is independent of that of the rocks on which it immediately rests—the cause of this apparent difficulty we are now to consider.

1°. I have already had occasion to explain to you in what way all rocks crumble more or less rapidly, and give origin to soils of various kinds. Were the surfaces of rocks uniformly level, and that of every country flat, the crumbled materials would generally remain on the spots where they were formed. But as already shown in the diagrams, inserted in pages 350 and 351, the rocks rarely lie in a horizontal position, but rest almost always more or less on their edges, and the surface in such a country as ours is often mountainous or hilly, and everywhere undulating. Hence the rains are continually washing off the finer particles from the higher, and bearing them to the lower grounds—and on occasions of great floods, vast quantities even of heavy materials are borne to great distances, and spread sometimes to a great depth and over a great extent of country.* Thus the spoils of one rocky formation are borne from their native seat and are strewed over the surface of other kinds of rock of a totally different character. The fragments of the granite, gneiss, and slate rocks of the high lands are scattered over the old red sand-stones which lie at a lower level—and those of the blue lime-stone mountains over the mill-stone grits, the coal measures, and the new red sand-stones, which stretch away from their feet.

2°. But the effects produced by this natural cause, though they may be judged of in kind, can never be estimated in degree by what we perceive in our own temperate climates—in our country of small rivers and gentle rains. How must such effects exceed in magnitude, in districts where,—as in the

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* Witness the still recent floods in Morayshire.

Ghauts, that separate the level land of the Malabar coast (the Concan) from the high table-land of the Deccan,—120 inches of rain occasionally fall in a single month, and 240 inches or 20 feet, on an average, every year from June to September! And to what vast distances must materials be transported by great rivers, such as the Mississippi, the River of Amazons, the Ganges, and the Indus, which maintain a course of thousands of miles, before they empty themselves into the sea? What necessary connection can the deposits of mud and sand which yearly collect at the mouths and in the places overflowed by the waters of these great rivers, have with the nature of the rocks on which these transported materials may happen to rest?

3°. But the constant motion of the waters of the sea washes down the cliffs on one coast, and carries away their ruins to be deposited, either in its own depths, or along other more sheltered shores. Hence sand banks accumulate—as in the centre of our own North Sea: or the land gains upon the water in one spot what it loses in another—as may be seen both on the shores of our own Island, and on the opposite coasts of Germany and France.

What necessary relation can the soils thus gained from the sea have to the rocks on which they rest? Suppose the bottom of the North Sea to become dry land, what necessary mineral relation would then exist between the soils which would gradually be formed on its hundreds of square miles of sand-banks, and the rocks on which those sand-banks immediately repose?

4°. Again, the sea, in general, carries with it and deposits in its own bosom the finest particles of clay, lime, and other earthy matters, and leaves along its shores accumulations of fine siliceous sand. This sand, when dry, the sea winds bear before them and strew over the land, forming sand hills and downs, sometimes of considerable height and of great extent. Such are to be seen here and there, in our own islands, but on the Eastern shores of the Bay of Biscay, and on the coasts of Jutland,—both exposed to violent sea winds,—they occur over much larger areas. Before these winds the light sands are continually drifting, and, year by year, advance further and further into the country, gradually driving lakes before them, swallowing up forests and cultivated fields, with the houses of the cultivators,* and burying alike the fertile soils and the rocks from which they were originally derived.

You have all read of the fearful sands of the African deserts, and of their destructive march when the burning winds awaken. History tells of populous cities and fertile plains, where nothing but blown sands are now to be seen, and geology easily leads us back to still more remote periods, when the broad zones of sandy desert were but narrow stripes of blown sand along the shores of the sea, or beds of comparatively loose sand-stone, which here and there came to the surface, and which the winds have gradually removed from their original site, and wafted widely over the land.

Wherever these sand-drifts spread, it will also be clear to you, that there may be no necessary similarity between the loose materials on the surface and the kind of rock over which these materials are strewed.

5°. Along with these I shall mention only one other great agent by which loose materials are gradually transported to considerable distances.

It is observed in elevated countries, where the snow never entirely melts, and where glaciers or sheets of ice hang on the mountain sides,—descending towards the plains as the winter's cold comes on, and again retreating towards the mountain tops at the approach of the summer's heat—that the edges of the glaciers bear before them into the vallies and deposit along their edges, banks or conical ridges of sand and gravel (Moraines). These consist of the fragments of the rocky heights, worn and rounded by the friction of the sheets of ice, beneath which they have descended from above, and from the edges of which, they finally escape into the plain.

These ridges of sand and gravel accumulate till some more sudden thaw than usual, or greater summer's heat arrives, when they are more or less completely broken up by the rush of water that ensues, and are dispersed over the subjacent tracts of level land.

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* In the Landes, the advance of the downs is estimated at 60 to 70 feet every year.

When the rocks are of a kind to rub down so fine as to form much mud as well as sand or gravel, the ridges are of a more clayey character. And where the edges of the glaciers descend to the borders of lakes or seas—as in the Tierra del Fuega—this mud is washed away and widely spread by the waters, while the gravel and sand remain nearer their original site; or, finally, when the ice actually overhangs the water, huge fragments break off now and then, —loaded with masses of gravel and sand, or even with rocks of large size,—which fragments float away often to great distances and drop their stony burdens here and there, as they gradually melt and disappear.

To these facts, let it be added, that recent geological researches, of a very interesting kind, tend to show that nearly all the elevated tracts of country in the temperate regions of Europe and America—in our own island among other localities—have been covered with such glaciers at a comparatively recent period, (geologically speaking), and that these glaciers have gradually retreated step by step to their present altitudes, halting here for a time, and lingering there;—and we shall find reason to believe that traces of transported materials—moved from their original site by this agent also—are to be looked for on almost every geological formation.

And such the geological observer finds to be in reality the case.

§ 6. *Of the occurrence of such accumulations in Great Britain, and of their influence in modifying the character of the soil.*

Such accumulations, for example, present themselves over a large portion of our own island. Thus, in Devonshire, the chalk and green sand are so completely covered by gravels, consisting of the fragments of older rocks from the higher grounds, mixed with chalk-flints and chert, that nearly the whole of this tract possesses one common character of infertility, and is widely covered with downs of furze and heath (De La Beche). In like manner the chalk, green sand, and plastic clay of a large portion of Norfolk and Suffolk, and of parts of the counties of Essex, Cambridge, Huntingdon, Bedford, Hertford, and Middlesex, are covered with till, (stiff unstratified clay), containing large stones, (boulders), or with gravels, in which are mixed fragments of rocks of various ages, which must have been brought sometimes from great distances, and perhaps from different directions (Lyell.) So over the great plain of the new red sandstone, in the centre and west of England—in Lancashire, Cheshire, Shropshire, Staffordshire, and Worcestershire—drifted gravels of various kinds are widely spread. It may indeed be generally remarked, that over the bottoms of all our great vallies, such drifted fragments are commonly diffused—that upon our wider plains, they are here and there collected in great heaps—and that on the lower lands that border either shore of our island, extensive deposits of clay, sand, or gravel, not unfrequently cover to a great depth the subjacent rocks.

The practical agriculturist will be able to confirm this remark, in whatever district almost he may live, by facts which have come within his own knowledge and observation. I shall briefly explain, by way of illustration, the mode in which such accumulations of drifted matter overlie the eastern or lower half of the county of Durham.

The eastern half of the county of Durham reposes, to the north of the city of Durham, chiefly upon the coal measures, (sand-stones and shales); to the south, chiefly on the magnesian lime-stone and the new-red sand-stone. These coal measures rise, here and there, into considerable elevations, as at Gateshead Fell near Newcastle, and Brandon Hill near Durham, where the rocks lie immediately beneath the surface, and are covered by comparatively little transported matter. The magnesian lime-stone, also, in many localities, starts up in the form of round hills or ridges, on which reposes only a poor thin soil, formed in great measure by the crumbling of the rock itself. Yet, generally speaking, this entire district is overspread with a thick sheet of drifted matter, consisting of clays, sands, and gravels.

This drift is made up of three separate layers, to be observed more or less distinctly in taking a general survey of the county, though there are few spots where they can all be seen reposing immediately one over the other.

1°. The upper layer consists of clays—on the higher grounds, poor, stiff, yellow—on the hill sides and slopes of the vallies, often darker in colour—but almost everywhere full of rounded trap boulders from a few pounds to many tons in weight. These are generally dug up when they obstruct the plough, and are sold for mending the roads at about 5s. a ton.* This clay varies in depth, from one or two, to fifty or sixty feet.

2°. Beneath the clay occurs an accumulation of fine, generally yellow, more rarely red, sand, intermixed with occasional layers and round hills of gravel—with frequent black streaks of rounded coal dust, and here and there with nests of rounded lumps of coal, from half an inch to five or six inches in diameter. This coal is sometimes so abundant as to be collected and sold for burning.

The gravels, where they overlie the coal measures, consist chiefly of rounded, and on the upper part occasionally of large angular masses of coal sand-stones—with here and there a fragment of trap, of mountain lime-stone, or of some of the older rocks to be met with in the mountainous district towards the west. Over the magnesian lime-stone, however, in the south-eastern division of the county, towards the foot of the south-eastern slope of the magnesian lime-stone hills, the gravels which exhibit in some places (Wynyard) an irregular stratification, contain many rounded masses of magnesian lime-stone, and even of new-red sand-stone—the evident debris of adjacent rocks long ago broken up.

3°. The undermost layer which rests immediately upon the subjacent rocks consists of a stiff unstratified blue clay often full of trap boulders, but containing also occasional large rounded masses of blue lime-stone—and smaller pebbles of quartz, of granite, and of the older slate rocks. In many localities this clay is wanting, and the sands or gravels rest immediately upon the carboniferous or magnesian lime-stone rocks—while in some tracts, both this and the upper clay appear to degenerate into a stony most unmanageable clayey gravel. I am not aware that the large whin (trap) boulders are ever met with in the beds of sand.

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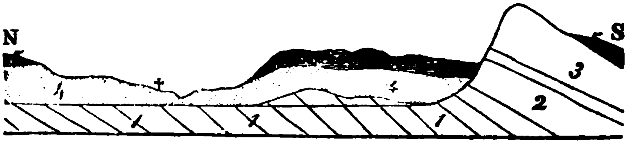
* In some parts of Northumberland these trap boulders are still more numerous. In the country which stretches between the north and south Tyne, the old grass fields are full of them. A friend of mine informs me that in ploughing out a nine-acre field on his estate in that district, there were dug out and carried off no less that 900 tons of such rolled stones, great and small!

The following diagram exhibits the mode in which these drifted materials present themselves in the neighbourhood of the City of Durham. The cross (†) indicates very nearly the site of Durham on the banks of the river Wear.



No. 1 represents the coal measures.

2. The lower new-red sand-stone, here soft and pale yellow.

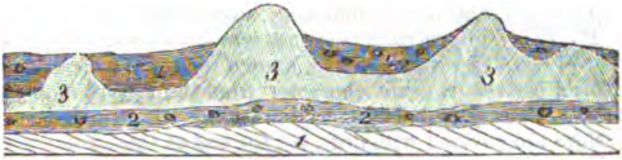
3. The magnesian lime-stone rising into a high escarpment from 3 to 6 miles south of the city.

4. Yellow loose sand—with rolled sand-stones and coal-drift—occasionally stratified. It forms the numerous picturesque round hills in the neighbourhood of the city, and varies from a few feet to not less than 120 feet in thickness.

5. Is the upper clay, with boulders. N indicates Framwellgate Moor, where it is only a few feet thick. At S, on the southern slope of the escarpment, it sometimes rests immediately on the rock as here represented—in which case it is difficult to decide whether it should be considered as the under or the upper clay—though in other spots both sand and clay, or gravel and clay, present themselves.

It will at once occur to you from the inspection of this diagram, that the general character of the soil in the county of Durham, wherever such accumulations of drifted matter occur, is not to be judged of from the nature of the rocks on which they are known to rest.

Another fact, not unworthy of your attention, is the rapid alternations of light and heavy soil, of sands or gravels and clays, which present themselves in the same district, I may say in the same farm, and often in the same field. This arises from the irregular thickness of the deposit of sand or gravel over which the upper clay rests. The surface of this sand is undulating, as if it had formed a country of round hills before the clay was deposited upon it. This appears in the following diagram, which represents the way in which the several layers are seen to occur in the Crindon cut on the Hartlepool railway :—



Here 1 is the magnesian lime-stone, not visible ; 2, the under clay, with boulders ; 3, the sand rising in round hills, and here and there piercing to the surface ; and 4, the upper boulder clay.

In the county of Durham it is a very usual expression that the tops of the hills are light turnip soil—but that they *fall off to clay*. Both the meaning and the cause of this are explained by the above diagram.

Nor is this mode of occurrence rare among the alternate sands and clays of which the superficial accumulations in various parts of the country consist. Nearly the same circumstances give rise to the rapid changes so frequently observed in the character of the soil, as we pass from field to field, not in this county only, but in various other parts of our island.

§ 7. *How far these accumulations of drift interfere with the general deductions of Agricultural Geology.*

Thus it appears, that over the eastern half of the county of Durham, and over large portions of other counties, the soils are found to rest upon and to derive their character from accumulations of drifted materials more or less different in their nature from the rocks that lie beneath.

But in the preceding lecture I have endeavoured to show you that soils are derived from the rocks on which they rest, and to impress upon you the close general relation which exists between the *kind of rocks* of which a country is composed, and the *kind of soils* by which its surface is overspread.

How are these apparent contradictions to be reconciled? How is any degree of order to be evolved out of this apparent confusion? Are the general indications of agricultural geology (Lecture xi., § 8.) still, in any degree, to be relied upon?

They are, and for the following, among other reasons:

1°. It is still *generally* true that where a considerable extent of country rests upon any known rock, the soil in that district derives its usual character from the nature of that rock. Thus though large portions of Cheshire and Lancashire are covered with drift, yet the soil of these counties, taken as a whole, has the general characters of the soils of the new-red sand-stone, which in that part of England is so largely developed.

2°. Where the drift overspreads any large area, it is found to become gradually mixed up with the fragments, large and small, of the rocks upon which it reposes. Thus in the neighbourhood of Durham, the round hills of sand and gravel with intermingled coal consist in great part of the ruins of the sand-stones of the country itself—while the clays, no doubt, are partly derived from the shale beds which occur intermingled with the sand-stones of the same coal measures. Hence the soils of the northern half of this county, in general, still partake of the usual qualities of those of the coal measures and mill-stone grit (pp. 365 and 366). In the western and higher part of the district they lie more immediately on the rocks from which they have been derived, while on the eastern half they rest on a mixture of the accumulated ruins of the same rocks, which have been transported by natural agents to a greater or less distance from their natural site.

It is true that there are mixed up with these many portions of other rocks brought from a still greater distance, but these bear but a small proportion to the entire mass, and hence have, generally speaking, but little influence in altering the mineral character of the whole.

3°. It may indeed be stated as generally true, that the greater proportion of the transported materials which lie upon any spot has been brought only a comparatively small distance. Thus the sands and gravels in the county of Durham—to the west of the magnesian lime-stone—consist chiefly of the fragments of the coal measures. East and south of the magnesian lime-stone escarpment (diagram, p. 396), they become mixed with rounded masses of this lime-stone. On the new-red sand-stone of the south-east of the county, they consist chiefly of magnesian lime-stone mixed with fragments of the red sand-stone—and on crossing the Tees, the debris of the lias hills begins to appear among them.

In countries, therefore, where drifted sands and gravels prevail on the surface, they generally consist of the fragments of rocks which lie at no great distance—generally towards the higher ground—the natural tendency being for the debris of one kind of rock, or of one formation, to *overlap* to a greater or less extent the surface of the adjoining rock or formation. By this overlapping, the *geographical* position of a given soil is removed to a greater or less distance beyond the line indicated by the *geological* position of the rocks from which it is derived. Thus, a coal measure soil may overspread part of the magnesian lime-stone—a red sand-stone soil may partially cover the lias, and so on—the general characters and distinctions of the soil peculiar to each rock being still preserved beyond the spaces upon which they have been accidentally intermingled.

4°. To this, and to each of the other statements above made, there are many local exceptions. For instance, what is true of sands and gravels, will not so well apply to the fine mud of which many clays are formed. Once commit these to the water, and if it has any motion, they may be transported to very great distances from their original site. Rivers, lakes, and seas, are the agents by which these extensive diffusions are effected. The former produce what are called alluvial formations or deposits; which are generally rich in all the inorganic substances that plants require, and hence yield rich returns to the agricultural labourer. They are usually, however, distinguished, and their boundaries marked, by the geologist—so that the soils which repose upon them do not contradict any of the general deductions he is prepared to draw, in regard to the general agricultural capabilities of a country, from the kind of rocks of which it consists.

Thus though the occurrence of extensive fields of drift over various parts of almost every country, does throw some further difficulty over the researches of the agricultural geologist, and requires from him the application of greater skill and caution before he pronounce with certainty in regard to the agricultural capabilities of any spot before he visit it—yet it neither contradicts the general deductions of the geologist nor the special conclusions he would be entitled to draw in regard to the ability of any country, when rightly cultivated, to maintain in comfort a more or less numerous population. The *political economist* may still, by a survey of the geological map of a country, pronounce with some confidence to what degree the agricultural riches of that country might by industry and skill be brought—and which districts of an entire continent are fitted by nature to maintain the most abundant population. The intending *emigrant* may still, by the same means, say in what new land he is most likely to find a propitious soil on which to expend his labour—or such mineral resources as will best aid his agricultural pursuits;—while a careful study of the geological map, of his own country, will still enable the skilful and adventurous *farmer* to determine in what counties he will meet with soils that are suited to that kind of practice with which he is most familiar—or which are likely best to reward him for the application of the newest and most approved methods of culture.

Still there are some aids to this kind of knowledge yet wanting. We have *geological* maps of all our counties, in which the boundaries of the several rocky formations are more or less accurately pointed out, and from these maps, as we have seen, much valuable agicultural information may be fairly deduced. We have also *agricultural* maps of many counties,* compiled with less care, and often with the aid of little geological knowledge. But agriculture now requires geological maps of her own—which shall exhibit not only the limits of the rocky formations, but also the nature and relative extent of the superficial deposits (drifts), on which the soils so often rest, and from which they are not unfrequently formed. These would afford a sure basis on which to rest our opinions in regard to the agricultural capabilities of the several parts of a county in which, though the rocks are the same, the soils may be very different. To the study of these drifted materials, in connection with the action of ancient glaciers (p. 392), the attention of geologists is at present much directed, and from their labours agriculture will not fail to reap her share of practical benefit—the geological survey, also, so ably superintended by Mr. De La Beche, is collecting and recording much valuable information in regard to the agricultural geology of the southern counties—but it is not unworthy the consideration of our leading agricultural societies—whether some portion of their encouragement might not be beneficially directed to the preparation of agricultural maps, which should represent, by different colours, the agricultural capabilities of the several parts of each county, based upon a knowledge of the soils and sub-soils of each parish or township, and of the rocks, whether near or remote, from which they have been severally derived.

Before leaving this subject, I will call your attention to one practical application of this knowledge of the extensive prevalence of drifts, which is not without its value. Being acquainted with the nature of the rocks in a country, and with its physical geography—that is, which of these rocks form the hills, and which the vallies or plains—we can predict, in general, that the materials of the hills will be strewed to a greater or less distance over the lower grounds, and that these lower soils will thus be more or less altered in their mineral character. And when the debris of the hills is of a more fertile character, than that of the rocks which form the plains, that the soils will be materially improved by this covering;—the soil of the mill-stone grit, for example, by the debris of the mountain lime-stone, or of a decayed green-stone or a basalt. On the other hand, where the higher rocks are more unfruitful, and the low lands are covered with sterile drifted sands brought down from the more elevated grounds—a knowledge of the nature of the subjacent rock may at once suggest the means of ameliorating and improving the unpromising surface-drift. Thus the loose sand of Norfolk is fertilized by the subjacent chalk marl; and even sterile heaths (Hounslow), on which nothing grew before, have, by this means, been made to produce luxuriant crops of every kind of grain.

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* As that of Durham in Bailey's *View of the Agriculture of the County of Durham, published in* 1810.

§ 8. *Of superficial accumulations of Peat.*

Of superficial accumulations, that of peat is one which, in the United Kingdom, covers a very large area. In Ireland alone, the extent of bog is estimated at 2,800,000 acres. None of the drifted materials we have considered, therefore, would appear so likely to falsify the predictions of the geologist, who should judge of the soils of such a country from information in regard to the rocks alone on which they rest—from a geological map for example—as the occurrence of these peat bogs. Yet there are certain facts connected with the formation of peat, which place him, in some measure, on his guard in reference even to accumulations of vegetable matter such as these.

1°. There is a certain range of temperature within which alone peat seems capable of being produced. Thus, at the level of the sea, it is never found nearer the equator than between the 40° and 45° of latitude; while its limit towards the poles appears to be within the 60th degree. It is a product, therefore, chiefly of the temperate regions.

Still on the equator itself, at a sufficient altitude above the sea, the temperature may be cool enough to permit the growth of peat. Hence, though on the plains of Italy, no peat is formed; yet on the higher Appenines, it may here and there be met with, among the marshy basins, and on the undrained mountain sides.

2°. The occurrence of stagnant water is necessary for the production of peat. Hence, on impervious beds of clay, through which the rains and springs can find no outlet, the formation of peat may be expected. Thus on the Oxford clay repose the fens of Lincoln, Cambridge, and Huntingdon (p. 360). On impervious rocks, also, peat bogs form for a similar reason. The new red sand-stone is occasionally thus impervious, and on it, among other examples, repose the Chat moss, the tract of peat, mostly in cultivation, which lies west of a line drawn between Liverpool and Preston, and the large extent of boggy country which stretches round the head of the Solway Firth. On the old red sand-stone, the mountain lime-stone, the slate, and the granite rocks, much peat occurs, and it is on these latter formations that the extensive bogs of Scotland and Ireland chiefly rest.

But though these two facts are of some value to the politician and to the geologist in indicating in what countries and on what formations peat may be expected to occur, yet they are of comparatively little importance to the practical agriculturist. It is of far more consequence to him that the moment he casts his eye upon the face of a country he can detect the presence or absence of peat—that none of the perplexities which beset the nature and origin of other superficial accumulations attach to this—that he can, at once, judge both of its source and of its agricultural capabilities. Though produced on a given spot, because rocks of a certain character exist there, yet its origin is always the same—its qualities more or less uniform,—the improvement of which is susceptible in some measure alike,—and the steps by which that improvement is to be effected, liable to variation, chiefly according as this or that ameliorating substance can be most readily obtained.

LECTURE XIII.

Exact chemical constitution of soils—their organic constituents—Analysis of soils—Composition of certain characteristic soils—Physical characters of soils.

In the two preceding lectures we have considered the general constitution and origin of soils, and their relation to the geological structure of the country in which they are found, and to the chemical composition of the rocks on which they rest. We have also discussed some of the causes of those remarkable differences which soils are known to present in their relations to practical agriculture. But a more intimate and precise acquaintance with the chemical constitution of soils is not unfrequently necessary to a complete understanding of the causes of these differences—of the exact effect which its chemical constitution has upon the fertility of a soil—and of the remedy which in any given circumstances ought to be applied.

Some persons have been led to expect too much from the chemical analysis of a soil, as if this alone were necessary at once to explain all its qualities, and to indicate a ready method of imparting to it every desirable quality,—while others have as far depreciated their worth, and have pronounced them in all cases to be *more curious than useful.*[*] The truth here, as on most other subjects, lies in the middle between these extreme opinions.

If you have followed me in the views I have endeavoured to press upon you in regard to the necessity of *inorganic* food to plants—which food can only be derived from the soil, and which must vary in kind and quantity with the species of crop to be raised,—you will at once perceive that the *rigorous* analysis of a soil may impart most valuable knowledge to the practical man in the form of useful suggestions for its improvement. It may indeed show that to apply the only available substances to the soil which are capable of remedying its defects, would involve an expense for which, in existing circumstances, the land could never give an equivalent return. Yet even in this latter case the results of analysis will not be without their value to the prudent man, since they will deter him from adding to his soil what he knows it already to contain, and will set him upon the search after some more economical source of those ingredients which are likely to benefit it the most.

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[*] Boussingault, *Annal. de Chim. et de Phys.* lxvii., p. 9.

It will be proper, therefore, to turn our attention briefly to the consideration of the exact chemical constitution of soils.

§ 1. *Of the exact nature of the organic constituents of soils, and of the mode of separating them.*

We have already seen[*] in a preceding lecture, that all soils contain a greater or less admixture of organic—chiefly vegetable—matter, the total amount of which may be very nearly determined by burning the *dried* soil at a red heat till all blackness disappears (p. 343). But this vegetable matter consists of several different chemical compounds, the nature and relative weights of which it is occasionally of consequence to be able to determine.

1°. *Humus.*—The general name of humus is given to the fine, brown, light powder which imparts their richness to vegetable moulds and garden soils. It is formed from the gradual decomposition of vegetable matter, exists in all soils, forms the substance of peat, and consists of a mixture of several different compounds which are naturally produced during the decay of the different parts of plants. It is distinguished into *mild*, *sour*, and *coaly* humus.

The *mild* gives a brown colour to water, but does not render it sour, gives a dark brown solution when boiled with carbonate of soda, evolves ammonia when heated with caustic potash or soda or with slaked lime, and leaves an ash when burned which contains lime and magnesia. The *sour* gives, with water, a brown solution of a more or less sour taste.[†] This variety is less favourable to vegetation than the former, and indicates a want of lime in the soil. The *coaly* humus gives little colour to water or to a hot solution of carbonate of soda, leaves an ash which contains little lime, occurs generally on the surface of very sandy soils, and is very unfruitful. It is greatly ameliorated by the addition of lime or wood ashes.

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[*] Lecture xi., p. 336.

[†] Or reddens vegetable blues.—See page 58.

2°. *Humic acid.*—When a fertile soil or a piece of dry peat is boiled with a solution of the common carbonate of soda of the shops, a brown solution, more or less dark, is obtained, from which, when diluted muriatic acid (spirits of salt) is added till the liquid has a distinctly sour taste, brown flocks begin to fall. This brown flocky matter is *humic acid.*

3°. *Ulmic acid.*—If, instead of a solution of carbonate of soda, one of caustic ammonia, the hartshorn of the shops, be digested upon the soil or peat by a gentle heat, a more or less dark brown solution is obtained, which, on the addition of muriatic acid, gives brown flocks as before, but which now consist of *ulmic acid.*

These two acids combine with lime, magnesia, alumina, and oxide of iron, forming compounds (salts) which are respectively distinguished by the names of *humates* and *ulmates.* They probably both exist, ready formed, in the soil in variable proportions, and in combination with one or more of the earthy substances above mentioned—lime, alumina, &c. They are produced by the decay of vegetable matter in the soil, which decay is materially facilitated by the presence of one or other of these substances, and by lime especially,—on the principle that the formation of acid compounds is in all such cases much promoted by the presence of a substance with which that acid may combine. They *predispose* organic substances to the formation of such acids, and consequently to the decomposition by which they are to be produced. These two acids consist respectively of

	Humic acid.	Ulmic acid.
Carbon	63	57
Hydrogen	6	4¾
Oxygen	31	38¼
	100	100

Some writers upon agriculture have supposed that these acids contribute very materially to the support of growing plants. But Liebig[*] has very properly objected to this opinion, that they are so very sparingly soluble in water that we cannot suppose them to enter directly into the roots —even were all the water they absorb to be saturated with them—in such quantity as to contribute in a great degree to the organic matter contained in almost any crop.[†]

We have indeed seen reason to conclude on other grounds, that only a small, though a variable, proportion of the carbon of plants is derived from the soil, yet of this proportion a certain quantity may enter by the roots in the form of one or other of these acids, or of their earthy compounds. They are readily soluble in ammonia; and animal manures which give off this compound in the soil may therefore facilitate their entrance into the roots of those plants which are cultivated by the aid of such manures. They are also soluble in carbonate of potash and carbonate of soda, which are contained in wood ashes and in the ash of weeds and of soils which are pared and burned. When these substances, therefore, are applied to the land, they may combine with, and, among their other beneficial modes of action, may serve to introduce, these acids in larger quantity into the plant.

When exposed to the air, the humates and ulmates contained in the soil undergo decomposition, give off carbonic acid, and are changed into carbonates. The admission of air into the soil facilitates this decomposition, which is supposed to be continually going forward—and it is in the form of this gas that plants are considered by some to imbibe the largest portion of that carbon for which they are indebted to the soil.

4°. *Crenic and Apocrenic acids.*—When soils are digested or washed with hot water, a quantity of organic matter is not unfrequently dissolved, which imparts to the water a brownish yellow colour. When the solution is evaporated to dryness, there remains besides the soluble saline substances of the soil, a variable portion of brown extractive looking matter also, which is a mixture of the two acids here named, with the ulmic and humic—all in combination with lime, alumina, and other bases. When this residue is dried at 230° F., the two latter acids, and their compounds, become insoluble, while the *crenates* and *apocrenates*, more especially the former, remain soluble in water, and may be separated by washing with this liquid.

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[*] *Organic Chemistry applied to Agriculture*, first edition, pp. 11 and 12.

[†] Ulmic acid requires 2500 times its weight of water to dissolve it—ulmate of lime 2000 times, and ulmate of alumina 4200 times—but all are still less soluble after they have been perfectly dried, or exposed to the action of a hard winter's frost. The ulmates of potash, soda, and alumina, are all dissolved in water with considerable ease.

These acids also are formed in the soil during the decay of vegetable matter. They are distinguished from the two previously described by containing nitrogen as an essential constituent, and by forming compounds with lime, &c., which are, for the most part, readily soluble in water. Hence they will both prove more nourishing to plants—in virtue of the nitrogen they contain—and in consequence of their solubility, will be able, where they exist, to enter more readily, and in greater abundance, into the roots than either the ulmic or the humic acid.

Owing to this solubility, also, they are more readily washed out of the soil by the rains, and hence are rarely present in any considerable quantity in specimens of soil which are submitted to analysis. They are frequently, however, met with in springs and in the drainings of the land. They have even been found in minute quantity in rain-water, and as they have also been detected in distilled water,* it is probable that they ascend into the air in very small proportion with the watery vapour that rises. This exhibits another form, therefore, in which the rains may minister to the growth of plants (see page 42).

Both acids form insoluble compounds with the peroxide of iron—and hence are found in combination with many of the ochrey deposits from ferruginous springs, and with the oxide of iron by which so many soils are coloured. The apocrenic acid has also a peculiar tendency to combine with alumina, with which it forms a compound insoluble in water, and in this state of combination it probably exists not unfrequently, especially in clayey soils.

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* Fürsten zu Salm-Horstmar. *Poggend. Annal.* liv., p. 254.

When heated with newly slaked quick-lime these acids give off ammonia and carbonic acid. By the action of the air, and of lime in the soil, they are probably decomposed in a similar manner, though with much less rapidity.

5°. *Mudesous acid* is another dark brown acid substance, which is also produced naturally in the soil. It resembles the apocrenic, in having a strong tendency to combine with alumina. In union with this acid it is slowly washed out of the soil by the rains, or filters through it when the water can find an outlet beneath. This is seen to be the case in some of the caves on the Cornish coast, where the waters that trickle through from above have gradually deposited on their roof and sides a thick incrustation of *mudesite of alumina*.*

Besides these acids, it is known that the malic and the acetic (vinegar) are occasionally produced in the soil during the slow decay of vegetable matter of different kinds. It is probable that many other analogous compounds are likewise formed—which are more or less soluble in water, and more or less fitted to aid in the nourishment of plants. There is every reason to believe, indeed, that organic substances in the soil pass through many successive stages of decomposition, at each of which they assume new properties, and become more or less capable of aiding in the support of living races. The subject is difficult to investigate, because of the obstacles which lie in the way of exactly separating from each other the small quantities of the different organic compounds that occur mixed up together in the soil. But it seems quite clear, that while some agricultural chemists have erred in describing the ulmic and humic acids as the *immediate* source of a large portion of the carbon of plants, others have no less mis-stated—as I apprehend—the true course of nature, who deny any *direct* influence to these and other substances of vegetable origin, and limit their use in the soil to the supply of carbonic acid only, which, on their ultimate decomposition, they are capable of yielding to the roots. The resources of vegetable life are not so limited; but as the human stomach can, and does, on occasion, convert into nourishment many different compounds of the same elements —so, no doubt, many of those organic compounds which are produced in the soil, or in fermenting manure during the decay of animal and vegetable bodies,—when once admitted, in consequence of their solubility, into the circulating system of plants,—are converted into portions of their substance and really do minister to their natural growth.

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* Known to mineralogists under the name of *Pigotite*.

Separation of these Organic Constituents.—1°. When on washing with hot water a soil imparts a colour to the solution, the liquid must be filtered and evaporated to perfect dryness. On treating with water what remains after the evaporation, the humic acid and humates remain insoluble, while the crenic and apocrenic acids are taken up by the water along with the soluble saline matter which the soil may have contained. By evaporating this second solution to perfect dryness, weighing the residue, and then heating it to dull redness in the air, the loss will indicate something more than the quantity of these acids present in the soil. By burning the dried insoluble matter, also, the quantity of humic acid present in it may in like manner be determined.

2°. After being washed with pure water, the soil is to be boiled with a solution of carbonate of soda, repeated once or twice as long as a brown solution, more or less dark, is obtained. Being filtered, and then rendered sour by muriatic acid, brown flocks fall, which being collected on the filter, perfectly dried and weighed, give the quantity of *humic acid* in the soil. As this dry humic acid generally contains some earthy matter, it is more correct to burn it, and to deduct the weight of the ash which may be left.

3°. The insoluble (coaly) humus still remains in the soil. On boiling it now in a solution of caustic potash for a length of time, and till a fresh solution ceases to become brown, the coaly humus is entirely dissolved—being converted according to Sprengel into humic acid. The addition of muriatic acid to this solution, till it has a sour taste, throws down the humic acid in the form of brown flocks, which may be collected, dried, and weighed as before.

4°. If there be any mudesite of alumina in the soil it is also dissolved by the potash, but is not thrown down when the solution is rendered sour by muriatic acid. The entire weight of organic matter in the soil being therefore determined by burning it in the air, after being perfectly dried, the difference between this weight and the sum of those of the humic acid and insoluble humus will be the proportion of the other acids present. Thus, if, by burning in the air, the soil lose 6 per cent., and give 2 per cent. of humic acid, and 2 of insoluble humus, there remain 2 per cent. for other organic substances in the soil.

In general it is considered sufficient to ascertain only the whole loss by burning, and the quantity taken up by carbonate of soda, the proportion of the other substances present being in most cases so small as to be capable of being precisely estimated by great precautions only.

§ 2. *On the exact chemical constitution of the earthy part of the soil.*

In reference to the general origin of soils—to their geological relations—and to the simplest mode of classifying them,—I have shown you that the earthy part of nearly all soils consists essentially of sand, clay, and lime (p. 338). But in reference to their chemical relations to the plants which grow, or may be made to grow, upon them, it is necessary, as you are now aware, to take a more refined and exact view of their constitution. This will appear by referring to three important principles established in the preceding lectures.

1°. That the ash of plants generally contains a certain sensible proportion of ten or twelve different inorganic substances (pp. 318 to 324).

2°. That they can, in general, only derive these substances from the soil which must, therefore, contain them (p. 265). And—

3°. That the fertility of a soil depends, among other circumstances, upon its ability to supply readily and in sufficient abundance all the inorganic substances which a given given crop requires (p. 335).

Now the quantity of some of these substances which is necessary to plants is so very small, that nothing but a refined analysis of a soil is capable, in many cases, of determining whether they are present in it or not—much less of explaining to what its peculiar defects or excellencies may be owing—what ought to be added to it in order to render it more productive—or why certain remarkable effects are produced upon it by the addition of mineral or animal manures.

Thus, for example, half a grain of gypsum in a pound of soil indicates the presence of nearly two cwt. in an acre, where the soil is a foot deep,—a quantity much greater than need be added to a soil, in which gypsum is almost entirely wanting, in order to produce a remarkable luxuriance in the red clover crop. In 100 grains of the soil, this quantity of gypsum amounts only to seven thousandths of a grain—($\frac{7}{1000}$, or 0·007 grs.)—a proportion which only a very carefully conducted analysis would be able to detect, and yet the detecting of which may alone be able to explain the unlike effects which are seen to follow the application of gypsum to different soils.

Again, the phosphoric acid is a no less necessary constituent of the soil, than the sulphuric acid contained in gypsum. This acid is generally in combination either with lime, with oxide of iron, or with alumina—and, as it is much more difficult even to detect than the sulphuric acid, requires more care and skill to determine its quantity with any degree of accuracy,—and is generally present even in fertile soils in a still smaller proportion—it is obvious that safe and useful conclusions can be drawn only from such analyses as have been made rigorously, according to the best methods, and with the greatest attention to accuracy.

There are cases, no doubt, where a rough analysis may be of use, where the cause of peculiarity is at once so obvious that further research is unnecessary—as where mere washing with water dissolves out a noxious substance, such as sulphate of iron (green vitriol). But such cases are comparatively rare, and it more frequently happens, that the cause of the special qualities of a soil only begins to manifest itself when a carefully conducted analysis approaches to its close. I shall, therefore, briefly describe to you the methods to be adopted, in order to arrive at these more accurate experimental results.*

§ 3. *Of the exact chemical constitution of certain soils, and of the results to be deduced from them.*

But the importance of this attention to rigorous analysis will more clearly appear, if I exhibit to you the constitution of a few of the numerous soils analyzed by Sprengel, in connection with the agricultural qualities and capabilities by which they are severally distinguished.†

I.—FERTILE SOILS.

Soils are fertile which contain a sufficient supply of all the mineral constituents which the plants to be grown upon them are likely to require.

1°. *Pasture.*—The following numbers exhibit the constitution of the surface soil in three fertile alluvial districts of Hanover, where the land had been long in pasture.

	Soil near Osterbruch.	From the banks of the Weser,	
		near Hoya.	near Weserbe.
Silica, Quartz, Sand, and Silicates.	84·510	71·849	83·318
Alumina	6·435	9·350	3·085
Oxides of Iron . . .	2·395	5·410	5·840
Oxide of Manganese . .	0·450	0·925	0·620
Lime	0·740	0·987	0·720
Magnesia	0·525	0·245	0·120
Potash and Soda extracted by water.	0·009	0·007	0·005
Phosphoric Acid . . .	0·120	0·131	0·065
Sulphuric Acid . . .	0·046	0·174	0·025
Chlorine in common Salt .	0·006	0·002	0·006
Humic Acid . . .	0·780	1·270	0·800
Insoluble Humus . . .	2·995	7·550	4·126
Organic matters containing nitrogen	0·960	2·000	1·220
Water	0·029	0·100	0·050
	100	100	100

These soils had all been long in pasture, the second is especially celebrated for fattening cattle when under grass.

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* As these methods of analysis involve considerable detail, I have transferred them to the Appendix.—(*See Appendix, p.* 41.)

† The following analysis are selected from a much greater number made by Sprengel, and embodied in his work on soils.—*Die Bodenkunde.*

It will be observed that in none of them is any of the mineral ingredients wholly wanting, though in all the quantity of potash and soda capable of being extracted by water is very small. This is ascribed to the fact of their having been long in pasture, during which the supply of these substances is gradually withdrawn by the roots of the grasses. It is well known how, in our ordinary soils, grass is often renovated—how the mosses, especially, are destroyed—by a dressing of wood ashes, which owe their effect to the alkali they contain. In the above soils the gradual decomposition of the '*silicates* would continue to supply a certain portion of alkaline matter for an indefinite period of time.

You will perceive that the soil which is the most celebrated for its *fattening* power, is also the richest in alumina, lime, phosphoric acid, sulphuric acid, and vegetable matter.

2°. *Arable.*—The following table exhibits the constitution of three soils, celebrated for yielding successive crops of corn for a long period without manure.

	1. From Nebtsein, near Olmutz, in Moravia.	2. From the banks of the Ohio, North America. Soil.	Subsoil.	3. From the polder of Alt-Arenberg, in Belgium.
Silica and fine Sand	77·209	87·143	94·261	64·517
Alumina . .	8·514	5·666	1·376	4·810
Oxides of Iron .	6·592	2·220	2·336	8·316
Oxide of Manganese	1·520	0·360	1·200	0·800
Lime . .	0·927	0·564	0·243	Carb. of Lime. 9·403
Magnesia . .	1·160	0·312	0·310	Carb. of Mag. 10·361
Potash chiefly combined with Silica .	0·140	0·120	0·240	0·100
Soda, ditto . .	0·640	0·025		0·013
Phosphoric Acid combined with Lime and Oxide of Iron,	0 651	0·060	trace	1·221
Sulphuric Acid in gypsum .	0·011	0·027	0·034	0·009
Chlorine in common salt .	0·010	0·036	trace	0·003
Carbonic Acid united to the Lime .	—	0·080	—	—
Humic Acid .	0·978	1·304	—	0·447
Insoluble Humus	0·540	1·072	—	—
Organic substances containing nitrogen.	1·108	1·011	—	—
	100	100	100	100

Of these soils, the first had been cropped for 160 years successively, without either manure or naked fallow. The second was a virgin soil, celebrated for its fertility. The third had been unmanured for twelve years, during the last nine of which it had been cropped with beans—barley—potatoes—winter barley and red clover—clover—winter barley—wheat—oats—naked fallow.

Though the above soils differ considerably, as you see, in the proportions of some of the constituents, yet they all agree in this—that they are not destitute of any one of the mineral compounds, which plants necessarily require in sensible quantity. You will also observe how comparatively small a proportion of vegetable matter, less than half a per cent., is contained in the fertile Belgian soil—a fact to which I shall by-and-bye re-call your attention.

3°. *Soils which have a natural source of fertility.*—Some soils, which by their constitution are not fitted to exhibit any great degree of fertility, or for a very long period, are yet, by springs or otherwise, so constantly supplied with soluble saline, and other substances, as to enable them to yield a succession of crops, without manure, and without apparent deterioration. Such is the case with the following soil from near Rothenfelde, in Osnabruck, which gives excellent crops, though manured only once in 10 or 12 years.

Silica and coarse Quartz Sand	86·200
Alumina	2·000
Oxides of Iron and a little Phosphoric Acid	2·900
Oxide of Manganese	0·100
Carbonate and a little Phosphate of Lime	4·160
Carbonate of Magnesia	0·520
Potash and Soda	0·035
Phosphoric Acid	0·020
Sulphuric Acid	0·021
Chlorine	0·010
Humic Acid	0·544
Insoluble Humus	3·370
Organic matter containing Nitrogen	0·120
	100

You will see that, although in this soil all the inorganic substances are really present, yet the potash and soda, the phosphoric and sulphuric acids, and the chlorine, are not in such abundance as to justify us in expecting it to grow any long succession of crops, without exhibiting the usual evidences of exhaustion. But it lies on the side of a hill which contains layers of lime-stone and marl, through which the surface waters find their way. These waters afterwards rise into the soil of the field, impregnated with those various substances of which the soil is in want, and thus, by a natural manuring, keep up a constant supply for each succeeding crop.

This example is deserving of your particular attention, inasmuch as there are many soils, in climates such as ours, which are yearly refreshed from a similar source. Few spring waters rise to the surface which are not fitted to impart to the soil some valuable ingredient, and which, if employed for the purposes of irrigation, would not materially benefit those lands especially, on which our pasture grasses grow. The same may also be said of the waters which are carried off in some places so copiously by drains. Whether these waters rise from beneath in springs, or falling in rain, afterwards sink through the soil, they in either case carry into the brooks and rivers much soluble matter, which the plants would gladly extract from them. On sloping grounds it would be a praiseworthy economy to arrest these waters, and, before they escape, to employ them in irrigation.

The fact that nature thus on many spots brings up from beneath, or down from the higher grounds, continual accessions of new soluble matter to the soil, will serve to explain many apparent anomalies, and to account for the continued presence of certain substances in small quantity, although year by year portions of them are carried off the land in the crops that are reaped, while no return is made in the shape of artificial manure. It will also in some instances account for the fact that, after a hard cropping, prolonged until the soil has become exhausted, a few years' rest will completely re-invigorate it, and render it fit to yield new returns of abundant corn. Other causes, as we shall hereafter see, generally operate in bringing about this kind of natural recovery, but there can be no question that in circumstances such as I have now adverted to, this recovery may be effected in a much shorter period of time.

4°. *Importance of depth and uniformity of soil.*—If the surface soil be of a fertile quality, ample returns will be sure from many cultivated crops. But where the subsoil is similar in composition to that of the surface—not only may the fertility of the land be considered as almost inexhaustible, but those crops also which send their roots far down will be able permanently to flourish in it. This fact is illustrated by the composition of the following soils from the neighbourhood of Brunswick:—

	1.		2.
	Soil.	Subsoil.	Subsoil.
Silica and fine Quartz Sand	94·724	97·340	90·035
Alumina	1·638	0·806	1·976
Oxides of Iron	1·960	1·126	5·815
Oxides of Manganese		0·075	0·240
Lime	1·028	0·296	0·022
Magnesia	trace	0·095	0·115
Potash and Soda	0·077	0·112	0·300
Phosphoric Acid	0·024	0·015	0·098
Sulphuric Acid	0·010	trace	1·399
Chlorine	0·027	trace	trace
Humic Acid	0·302	0·135	—
Insoluble Humus	0·210	—	—
	100	100	100

The first of these soils produced excellent crops of all deep-rooted plants—lucerne, sainfoin (esparsette), hemp, carrots, poppies, &c.—and with the aid of gypsum, red clover, and leguminous plants (vetches, peas, and beans), in great luxuriance. The former of these facts is explained by the great similarity in constitution which exists between the surface and the under soils. To deep-rooted plants also the magnesia, in which the surface is deficient, is capable of being supplied by the under soil. The effect of the gypsum is accounted for by the almost total absence of sulphuric acid in the subsoil, but which the application of gypsum has introduced into the upper soil.

The second soil was taken from a field in which sainfoin died regularly in the second or third year after it was planted. This was naturally attributed to something in the subsoil. And by the analyses above given, it was found to contain much sulphuric acid in combination with oxide of iron, forming sulphate of iron (green vitriol). This salt being noxious to plants, began to act upon the crop of sainfoin as soon as the roots had gone so deep as to draw sufficient supplies from the subsoil, and it thus gradually poisoned them, so that they died out in two or three years.

II.—BARREN OR UNFRUITFUL SOILS.

Soils are unfruitful or altogether barren, either when they contain too little of one or more of the inorganic constituents of plants, or when some substance is present in them in such quantity as to become hurtful or poisonous to vegetation. The presence of sulphate of iron in the subsoil just described is an illustration of the latter fact—in what way the *deficiency* of certain substances really does affect the agricultural capabilities of the soil will appear from the following analyses :—

	1. Moor-land soil, near Aurich, East Friesland.		2. Another soil, from the same neighbourhood.	3. Sandy soil, near Wettingen, in Lüneburg.	4. Soil on the Muschelkalk, near Mühlhausen.
	Soil.	Subsoil.			
Silica & Quartz Sand	70·576	95·190	61·576	96·000	77·780
Alumina	1·050	2·520	0·450	0·500	9·490
Oxides of Iron . . .	0·252	1·460	0·524	2·000	5·800
Oxide of Manganese .	trace	0·048	trace	trace	0·105
Lime	do.	0·336	0·320	0·001	0·866
Magnesia	0·012	0·125	0·130	trace	0·728
Potash	trace	0·072	trace	do.	trace
Soda	do.	0·180	do.	do.	do.
Phosphoric Acid . .	do.	0·034	do.	do.	0·003
Sulphuric Acid . .	do.	0·020	do.	do.	trace
Carbonic Acid . .	—	—	—	—	0·200
Chlorine	trace	0·015	trace	trace	trace
Humic Acid . . .	11·910	—	11·470	0·200	0·732
Insoluble Humus . .	16·200	—	25·530	1·299	0·200
Water	—	—	—	—	4·096
	100	100	100	100	100

Each of these analyses is deserving of attention.

1°. That the barrenness of the moor-land soils (1 and 2) is to be attributed to their deficiency in the numerous substances of which they contain only traces, may almost be said to be proved by the fact—one long recognised and acknowledged on many of our own moor-lands and peaty soils—that when dressed with a covering of the subsoil they become capable of successful cultivation. The analysis of the subsoil in the second column shows that it contains *all those mineral constituents in which the soil itself is defective*—and to the effect of these, therefore, the improvement produced upon the soil by bringing it to the surface, is altogether to be attributed.

2°. The sandy soil, No. 3, is evidently barren for the same reason as the moor-land soils, 1 and 2. The soil No. 4 rests on lime-stone, and was mixed with 7 per cent. of lime-stone gravel, and contains a great number of the substances which plants require—but its unfruitfulness is to be ascribed to the want of potash and soda, of sulphuric acid and of chlorine. Wood ashes and a mixture of common salt with gypsum or sulphate of soda, would probably have remedied these defects.

3°. Among the fertile soils to which I recently directed your attention (p. 414), was one from Belgium, in which the proportion of organic matter was less than half a per cent. of its whole weight. In the above table, on the other hand, we have two nearly barren soils, containing each 11 per cent. of humic acid, besides a much larger proportion of insoluble organic matter. It is obvious, therefore, that the fertility of a soil is not dependant upon its containing this or that proportion of vegetable matter, either in a soluble or an insoluble form. It is certainly true that many very fertile soils do contain a considerable quantity of organic matter, in a form in which it may readily yield nourishment to the roots of plants. Yet such soils are not fertile merely in consequence of the presence of this organic matter, as a source of *organic* food to the plant. It may be present, and yet the soils, like those above-mentioned, may remain barren. Where soils become fertile apparently by the long accumulation of such vegetable matter in the soil, it is not *merely* because of the increase of purely organic substances such as the humic and ulmic acids, but, because, as I have already had occasion to mention to you, the decaying vegetable matter which produces them contains *also*, and yields to the soil, a considerable abundance of some of those inorganic substances which plants necessarily require. The organic matter is an indication of their presence in such soils. But they may be present without the organic matter. They may either be duly proportioned in the soil by nature—or they may be artificially mixed with it, and then this use of the organic matter may be dispensed with. It is of more importance to bear this in mind, because not only vegetable physiologists, but some zealous chemists also, have laid great stress upon the quantity of soluble and insoluble organic matter contained in a soil, and have been led to consider it as a safe index of the relative fertility of different soils.

The history of science shows, by many examples, that those men who adopt extreme views,—who attempt to explain all phenomena of a given kind, by reference to a single specific cause—have ever been of very great use in the advancement of *certain* knowledge. Their arguments, whether well or ill founded, lead to discussion, to further investigation, to the discovery of exceptional cases, and, finally, to the general adoption of modified views which recognise the action of each special cause in certain special cases, but all in subordination to some more general principle.

Thus, if some ascribe the fertility of the soil to the presence of the alkalies in great abundance, others to that of the phosphates, others to that of lime, others to that of alumina, and others, finally, to that of vegetable matter in a soluble state—all these extreme opinions are reconciled, and their partial truths recognised, in one general principle, that *a soil to be fertile must contain all the substances which the plant we desire to grow can only obtain from the soil, and in such abundance as readily to supply all its wants; while at the same time it must contain nothing hurtful to vegetable life.*

III.—SOILS CAPABLE OF IMPROVEMENT BY THE ADDITION OF MINERAL MATTER.

On the principle above stated depends in very many cases the mode of improving soils by the addition of mineral substances, as well as the method of explaining the remarkable effects occasionally produced by their mixture with the land. The following analyses will place this matter in a clearer light:—

	1. Soil near Padingbüttel, on the Weser.	2. Near Drakenburg, on the Weser.	3. Near Gandersheim, in Brunswick.	4. Near Brunswick.
Silica and Quartz Sand .	93·720	92·014	90·221	95·698
Alumina . . .	1·740	2·652	2·106	0·504
Oxide of Iron . . .	2·060	3·192	3·9 1	2·496
Oxide of Manganese .	0·320	0·480	0·960	trace
Lime . . .	0·121	0·243	0·539	0·038
Magnesia . . .	0·700	0·700	0·730	0·147
Potash (chiefly in combination with Silica .	0·062	0·125	0·066	0·090
Soda (do.) . . .	0·109	0·026	0·010	
Phosphoric Acid . .	0·103	0·078	0·367	0·164
Sulphuric Acid . .	0·005	trace	trace	0·007
Chlorine in common Salt	0·050	trace	0·010	0·010
Humic Acid . . .	0·890	0·340	0·900	0·626
Other Organic matter .	0·120	0·150	0·140	0·220
	100	100	100	100

The first of these soils produces naturally *beautiful* red clover—the second produces *very bad* red clover. On comparing the constitution of the two soils, we see the second to be deficient in sulphuric acid and chlorine. A dressing of gypsum and common salt would supply these deficiencies, and render it capable of producing this kind of clover. The third soil is remarkable for growing luxuriant crops of pulse, when manured with gypsum. The almost total absence of sulphuric acid explains this effect. The fourth soil was greatly improved by soap-boiler's ash, which supplied it with lime, magnesia, manganese, and other substances.

I need not further multiply examples to show you how much real knowledge is to be derived from a rigidly accurate analysis, not only in regard to the agricultural capabilities of a soil, but also in regard to the natural and necessary food of plants, and to the manner in which mineral manures act in promoting and increasing their growth. The illustrations I have already presented will satisfy you—

1°. That a fertile soil must contain all the inorganic constituents which the plant requires, and none that are likely to do it an injury.

2°. That if the addition of a given manure to the soil render it more fertile—it is because the soil was defective in one or more of those substances which the manure contained.

3°. That if a given application to the land fail to improve it—of gypsum, of bone-dust, of common salt, for example—it is because enough of the substance applied is already present, or because something else is still wanting to render the previous additions available.

4°. That the result of extended experience in our country, that the clay soils are best for wheat, and sandy soils, such as that of Norfolk, for barley, is not to be considered as anything like a law of nature, setting aside the clay land for the special growth of wheat, and denying to the sandy soils the power of yielding abundant crops of this kind of grain. Almost every district can present examples of well cultivated fields, where the contrary is proved—and the wheat crops which are yearly reaped from the sandy plains of Belgium, demonstrate it on a more extended scale.

Chemically speaking, a soil will produce any crop abundantly, provided it contain an ample supply of all that the crop we wish to raise may happen to require. But in practice, soils which do contain all these substances plentifully, are yet found to differ in their power of yielding plentiful returns to the husbandman. Such differences arise from the climate, the exposure, the colour, the fineness of the particles, the lightness or porosity of the soil—from the quantity of moisture it is capable of retaining, or from some other of its numerous physical properties. These physical properties, therefore, it is necessary shortly to consider.

§ 4. *Of the physical properties of soils.*

To the physical properties of soils, was formerly ascribed a much more fundamental importance than we can now attach to them. Crome and Schübler regarded the fertility of a soil as entirely dependant upon its physical properties. Influenced by this opinion, the former published the results of an examination of numerous soils in the Prussian provinces, which are now possessed of no scientific interest; because they merely indicate the amount of clay, sand, and vegetable matter which these soils severally contained.* The latter completed a very elaborate examination of the physical properties of soils, which is very useful and instructive;† but the defective nature of which, in accounting for their agricultural capabilities, became evident to the author himself, when the more correct and scientific views of Sprengel, illustrated in the preceding section, afterwards became known to him. In giving, therefore, their due weight to the physical properties, we must not forget that in nature they are subordinate to the chemical constitution of soils. Plants *may* grow upon a soil, whatever its physical condition—if all the food they require be within their reach—while, however favourable the physical condition may be, nothing can vegetate in a healthy manner, if the soil be deficient in some necessary kind of food, or contain what is destructive to vegetable life.

Of the physical properties of soils the most important are their density, their power of absorbing and retaining water and air, their capillary action, their colour, and their consistence or adhesive power. There are one or two others, however, to which it will be necessary shortly to advert.

I.—MECHANICAL RELATIONS OF SOILS.

1°. *The density and absolute weight of a soil.*—Some soils are much heavier than others, not merely in the ordinary sense of heavy and light, as denoting clayey and sandy soils, but in reference to the absolute weight of equal bulks. Thus a cubic foot of dry

Siliceous or Calcareous Sand—weighs about	110 lbs.
Half Sand and half Clay	95
Of common arable Land, from . .	80 to 90
Of pure agricultural Clay (page 340) .	75
Of garden Mould, richer in vegetable matter	70
Of a peaty Soil, from	30 to 50

Sandy soils, therefore, are the heaviest. The weight diminishes with the increase of clay, and lessens still further as the quantity of vegetable matter augments.

In practice, the denser a soil is, the less injury will be done to the land by the passage of carts and the treading of cattle in the ordinary operations of husbandry. In a theoretical point of view it is of consequence to vegetation, chiefly in so far as, according to the experiments of Schübler, the denser soils retain their warmth for a longer period when the sun goes down, or a cold wind comes on. Thus a peaty soil will cool as much in an hour and a half as a pure clay in two or a sand in three hours.

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* Recorded in his *Grundsätze der Agricultur Chemie.*

† *Der Boden und sein verhältniss zu den Gewächsen.*

2°. *Of the state of division of the constituent parts of the soil.*—With the relative weight of different soils, their state of division is in some degree connected. Some soils consist of an admixture of exceedingly fine particles both of sand and clay—while in others, coarse sand, stones and gravels, largely predominate. There can be no doubt that the state of a soil in this respect has a material influence upon its productive character, and consequently upon its money value, since the labours of the husbandman in lands of a stiffer and more coherent nature, are chiefly expended in bringing them into this more favourable powdery condition. In the description and examination of a soil, therefore, this property ought by no means to be passed lightly over—since it is one in regard to which a mere chemical analysis gives us little or no information.

In some parts of the country the farmer diligently gathers the stones off his land, while in others the practice is condemned as hurtful to the arable crops. The latter fact is explained by supposing that these stones in winter afford shelter to the winter-corn, and in warmer seasons protect the ground in some degree from the drying winds, and retain beneath them a supply of moisture of which the neighbouring roots can readily avail themselves.

3°. *Firmness and adhesive power of soils.*—When soils dry in the air they cohere and become hard and stiff in a greater or less degree. Pure siliceous sands, alone, do not at all cohere when dry—while pure clays become hard and very difficult to pulverize. In proportion to the quantity of sand with which the latter are mixed, do their tenacity and hardness diminish. The difficulty of reducing clays to a fine powder in the open field, or of bringing them into a good tilth, may be overcome, therefore, by an admixture of sand or gravel, but there are few localities where the expense of such an operation does not present an insurmountable obstacle. Thorough draining, however, subsoil ploughing, and careful tillage, will gradually bring the most refractory soils of this character into a condition in which they can be more perfectly and more economically worked.

Soils also adhere to the plough in different degrees, and, therefore, present a more or less powerful obstruction to its passage. All soils present a greater resistance when *wet* than when *dry*, and all considerably more to a wooden than to an iron plough. A sandy soil when wet offers a resistance to the passage of agricultural implements, equal to about 4 lbs. to the square foot of the surface which passes through it—a fertile vegetable soil or rich garden mould about 6 lbs., and a clay from 8 to 25 lbs. to the square foot. These differences will naturally form no inconsiderable items in the calculations of the intelligent farmer when he estimates the cost of working, and the consequent rent he can afford to pay for this or that soil, otherwise equal in value.

II. RELATIONS OF SOILS TO WATER.

1°. *Power of imbibing moisture from the air.*—When a portion of soil is dried carefully over boiling water, or in an oven, and is then spread out upon a sheet of paper in the open air, it will gradually drink in watery vapour from the atmosphere, and will thus increase in weight. In hot climates and in dry seasons this property is of great importance, restoring as it does, to the thirsty soil, and bringing within the reach of plants, a portion of the moisture which during the day they had so copiously exhaled.

Different soils possess this property in unequal degrees. During a night of 12 hours, and when the air is moist, according to Schübler, 1000 lbs. of a perfectly dry

Quartz Sand will gain	0 lbs.	Clay Loam . .	25 lbs.
Calcareous Sand .	2	Pure Agricultural Clay	37
Loamy Soil . .	21		

and peaty soils, or such as are rich in vegetable matter, a still larger quantity.

Sir Humphry Davy found this property to be possessed in the highest degree by the most fertile soils. Thus, when made perfectly dry, 1000 lbs. of a

Very fertile Soil from East Lothian gained in an hour	18 lbs.
Very fertile Soil from Somersetshire	16
Soil worth 45s. per acre from Mersea, in Essex	13
Sandy Soil worth 28s., from Essex	11
Coarse Sand worth only 15s.	8
Soil of Bagshot Heath	3*

Fertile soils, therefore, possess this property in a very considerable degree, and, though we cannot, by determining this property alone, infer with safety what the fertility of a soil is likely to prove—since peaty soils and very strong clays are still more absorbent of moisture, and since this property is only remotely connected with the special chemical constitution of a soil—yet among arable, sandy, and loamy lands it certainly does, as Sir Humphry Davy states, afford *one* means of judging of their relative agricultural capabilities.

2°. *Power of containing or holding water.*—If water be poured drop by drop upon a piece of chalk or of pipe-clay, it will sink in and disappear, but if the dropping be continued, the pores of the earth will by degrees become filled with water, and it will at length begin to drop out from the under part as it is added above. This property is exhibited in a certain degree by all soils. The rain falls and is drunk in, the dew also descends, and is thus taken possession of by the soil. But after much rain has fallen, the earth becomes saturated, and the rest either runs off from the surface or sinks through to the drains. This happens more speedily in some soils than in others. Thus from 100 lbs. of dry soil, water will begin to drop—if it be a

Quartz Sand, when it has absorbed	25 lbs.
Calcareous Sand	29
Loamy Soil	40
English Chalk	45—J.
Clay Loam	50
Pure Clay	70

but a dry peaty soil will absorb a very much larger proportion (Schübler), before it suffers any to escape. Useful arable soils are found to be capable of thus containing from 40 to 70 per cent. of their weight of water. If the quantity be less than this, the soils are said to be best adapted for pine plantations, if greater, for laying down to grass.

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* Sir H. Davy's works, vol. vii., p. 326.

In dry climates this power of holding water must render a soil more valuable, whereas in climates such as ours, where rains rather over-abound, a simple determination of this property will serve to indicate to the practical farmer on which of his fields it is most important to him, in reference to surface water, that the operation of draining should be first and most effectually performed. The more water the soil contains within its pores, the more it has to part with by subsequent evaporation; and, therefore, the colder it is likely to be. The presence of this water also excludes the air in a great degree, so that for these, as well as for other reasons, it is desirable to afford every facility for the speedy removal of the excess of water from such soils as absorb it, and are capable of containing it, in a very large proportion.

3°. *Power of retaining water when exposed to the air.*—Unless when rain or dew are falling, or when the air is perfectly saturated with moisture, watery vapour is constantly rising from the surface of the earth. The fields, after the heaviest rains and floods, gradually become dry, though this, as every farmer has observed, takes place in some of his fields with much greater rapidity than in others. Generally speaking, those soils which are capable of arresting and *con*taining the largest portion of the rain that falls, *re*tain it also with the greatest obstinacy, and take the longest time to dry. Thus a sand will become as dry in one hour as a pure clay in three, or a piece of peat in four hours. This, therefore, not only explains, and shows the correctness of, the well-known distinctions of *warm* and *cold* soils, but exhibits another strong argument in favour of a perfect drainage of stiff soils and of such as contain a large proportion of decaying vegetable matter.

4°. *Capillary power of the soil.*—When water is poured into the sole of a flower-pot, the soil gradually sucks it in and becomes moist even to the surface. The same takes place in the soil of the open fields. The water from beneath—that contained in the subsoil—is gradually sucked up to the surface. Where water is present in excess, this capillary action, as it is called, keeps the soil always moist and cold.

The tendency of the water to ascend, however, is not the same in all soils. In those which, like sandy soils and such as contain much vegetable matter, are open and porous, it probably ascends most freely, while stiff clays will transmit it with less rapidity. No precise experiments, however, have yet been made upon this subject, chiefly, I believe, because this property of the soil has not hitherto been considered of such importance as it really is, to the general vegetation of the globe. Let us attend a little to this point.

I have already drawn your attention to the fact, that the specimens of soil which are submitted to analysis generally contain very little saline matter, and yet that in a crop reaped from the same soil a very considerable proportion exists. This I have attributed to the action of the rains which dissolve out the soluble saline matter from the surface soil, and as they sink, carry it with them into the subsoil; or from sloping grounds, and during very heavy rains, partly wash it into the brooks. Hence from the proportion of soluble matter present at any one time in the surface soil, we cannot safely pronounce as to the quantity which the whole soil is capable of yielding to the crop that may be grown upon it. For when warm weather comes and the surface soil dries rapidly, then by capillary action the water rises from beneath, bringing with it the soluble substances that exist in the subsoil through which it ascends. Successive portions of this water evaporate from the surface, leaving their saline matter behind them. And as this ascent and evaporation go on as long as the dry weather continues, the saline matter accumulates about the roots of plants so as to put within their reach an ample supply of every soluble substance which is not really defective in the soil. I believe that in sandy soils, and generally in all light soils, of which the particles are very fine, this capillary action is of great importance, and is intimately connected with their power of producing remunerating crops. They absorb the falling rains with great rapidity, and these carry down the soluble matters as they descend—so that when the soil becomes soaked, and the water begins to flow over its surface, the saline matter being already buried deep, is in little danger of being washed away. On the return of dry weather, the water re-ascends from beneath and again diffuses the soluble ingredients through the upper soil.

In climates, such as ours, where rains and heavy dews frequently fall, and where the soil is seldom exposed for any long period to hot summer weather unaccompanied by rain, we rarely see the full effect of this capillary action of the soil. But in warm climates, where rain seldom or never falls, the ascent of water from beneath, where springs happen to exist in the subsoil, goes on without intermission. And as each new particle of water that ascends brings with it a particle, however small, of saline matter (for such waters are never pure), which it leaves behind when it rises into the air in the form of vapour, a crust, at first thin, but thickening as time goes on, is gradually formed on the surface of the soil. Such crusts are seen in the dry season—in India, in Egypt, and in many parts of Africa and America. In hot, protracted summers they may be seen on the surface of our own fields, but they disappear again with the first rains that fall. Not so where rains are unknown. And thus on the arid plains of Peru, and on extensive tracts in Africa, a deposit of saline matter, sometimes many feet in thickness, is met with on the surface of wide plains, in the hollows of deep vallies, and on the bottoms of ancient lakes. Such an incrustation, probably so formed, is the bed of nitrate of soda in Peru, from which all our supplies of that salt are drawn, such are the deposits of carbonate of soda (trona) which form a considerable article of commerce in some parts of Africa, and such the mineral soda (urao) extracted from the soil in the South American State of Columbia.

5°. *Contraction of the soil on drying.*—Some soils in dry weather diminish very much in bulk, shrink in, and crack. Thus after being soaked by rain, pure clay and peaty soils diminish in bulk about one-fifth when they are again made perfectly dry—while sand has the same bulk in either state. The more clay or vegetable matter, therefore, a soil contains, the more it swells and contracts in alternate wet and dry weather. This contraction in stiff clays can scarcely fail to be occasionally injurious to young roots from the pressure upon the tender fibres to which it must give rise, while in light and sandy soils the compression of the roots is nearly uniform in all weathers, and they are undisturbed in their natural tendency to throw out off-shoots in every direction. Hence another good quality of light soils, and a less obvious benefit which must necessarily result from rendering soils less tenacious by admixture or otherwise.

III.—RELATIONS OF THE SOIL TO THE ATMOSPHERE.

Power of absorbing oxygen and other gaseous substances from the air.—1°. The importance of the oxygen of the atmosphere, first to the germination of the seed, and afterwards to the growth of the plant, I have already sufficiently insisted upon. It is of consequence, therefore, that this oxygen should gain access to every part of the soil, and thus to all the roots of the plant. This access can be facilitated by artificially working the land, and thus rendering it more porous. But some soils, in whatever state they may be in this respect, have been found to absorb oxygen with more rapidity, and in larger quantity, than others. Thus clays absorb more oxygen than sandy soils, and vegetable moulds or peats more than clays. This difference depends in part upon the natural porosity of these different soils, and in part also upon the chemical constitution of each. If the clay contain iron or manganese in the state of first or *prot*-oxides, these will naturally absorb oxygen for the purpose of combining with it,—while the decaying vegetable matter will in like manner, in such as contain it largely, drink in much oxygen to aid their natural decomposition.

2°. Besides the gases, oxygen and nitrogen, of which the air principally consists, the soil absorbs also carbonic acid from the atmosphere, and portions of those various vapours,—whether of ammonia and other effluvia which rise from the earth, or of nitric acid formed in the air,—and these, in the opinion of some chemists, contribute very materially to its natural fertility. This, however, is very much a matter of conjecture, and no experiments have been made as to the relative capabilities of different soils thus to extract vegetable food from the surrounding air. One fact, however, seems to be clearly ascertained, that all soils, namely, absorb gaseous substances of every kind most easily and in the greatest abundance when they are in a moist state. The fall of rains, or the descent of dew, therefore, will favour this absorption in dry seasons, and it will also be greatest in those soils which have the power of most readily extracting watery vapour from the air during the absence of the sun. Hence the influence of the dews and of gentle showers on the progress of vegetation, is not limited to the mere supply of water to the thirsty ground, and of those vapours which they bring with them as they descend to the earth, but is partly due also to the power which they impart to the moistened soil, of extracting for itself new supplies of gaseous matter from the surrounding atmosphere.

IV.—RELATIONS OF THE SOIL TO HEAT.

There are some of the relations of soils to heat, which have considerable influence upon their power of promoting vegetation. These are the rapidity with which they absorb heat from the air, the temperature they are capable of attaining under the direct action of the sun's rays, and the length of time during which they are able to retain this heat.

1°. *Power of absorbing heat.*—It is an important fact, in reference to the growth of plants, that during sunshine, when the sun's rays beat upon it, the earth acquires a much higher temperature than the surrounding air. This temperature very often amounts to 110° and sometimes to nearly 150°, while the air in the shade is between 70° and 80° only. Thus the roots of plants are supplied with that amount of warmth which is most favourable to their rapid growth.

Dark-coloured—such as black and brownish red—soils absorb the heat of the sun most rapidly, and therefore become warm the soonest. They also attain a higher temperature—by a few degrees only, however (3° to 8°),—than soils of other colours, and thus, under the action of the same sun, will more rapidly promote vegetation. In climates, such as ours, where the presence of the sun is often wished for in vain in time of harvest, this property of the soil possesses a considerable economical value. In other parts of the world, where sun-shine abounds, it becomes of less importance.

Every one will understand that the above differences are observed among such soils only as are exposed to the same sun under the same circumstances. Where the exposure or aspect of the soil is such as to give it the prolonged benefit of the sun's rays, or to shelter it from cold winds, it will prove more propitious to vegetation than many others less favourably situated, though darker in colour and more free from superfluous moisture.

2°. *Power of retaining heat.*—But soils differ more in their power of retaining the heat they have thus absorbed. You know that all hot bodies, when exposed to the air, gradually become cool. So do all soils ; but a sandy soil will cool more slowly than a clay, and the latter than a soil which is rich in vegetable matter. The difference, according to Schübler, is so great, that a peaty soil cools as much in one hour as the same bulk of clay in two, or of sand in three hours. This may no doubt have considerable influence upon growing crops, inasmuch as, after the sun goes down, the sandy soil will be three hours in cooling, while the clays will cool to the same temperature in two, and rich vegetable mould in one hour. But on those soils which cool the soonest, dew will first begin to be deposited, and it is doubtful, where the soils are equally drained, whether, in summer weather, the greater proportion of dew deposited on the clays and vegetable moulds, may not more than compensate to the parched soil—for the less prolonged duration of the elevated temperature derived from the action of the sun's rays. It is also to be remembered, that vegetable soils at least absorb the sun's heat more rapidly than the lighter coloured sandy soils, and thus the plants which grow in the former, which is sooner heated, may in reality be exposed to the highest influence of the sun's warmth—for at least as long a period as those which are planted in the latter.

The only power we possess over these relations of soils to heat, appears to be, that by top-dressing with charcoal, with soot, or with dark-coloured composts, we may render it more capable of rapidly absorbing the sun's heat, and by admixture with sand, more capable of retaining the heat which it has thus obtained.

Such are the most important of the physical properties of soils. Over some of them, the skilful farmer possesses a ready control. He can drain his land, and thus render it cheaper to work and more easy to reduce to a fine powder. He can plough, subsoil, and otherwise work it well, and thus can make it more open and porous, more accessible both to air and water. When it is light and peaty, he can lay heavy matter over it—clay, and sand, and lime-stone rubble—and can thus increase its density. He can darken its colour in some localities with peat composts, and can thus make it more absorbent of heat and moisture, as well as more retentive of the rain that falls. But here his power ends, and how far any of the changes within his power can be *prudently* attempted will depend upon the expense which, in any given locality, the operation would involve. And even after he has done all which mere mechanical skill can suggest, the soil may still disappoint his hopes, and refuse to yield him remunerating crops of corn.

"A soil," says Sprengel, "is often neither too heavy nor too light, neither too wet nor too dry, neither too cold nor too warm, neither too fine nor too coarse;—lies neither too high nor too low, is situated in a propitious climate, is found to consist of a well-proportioned mixture of clayey and sandy particles, contains an average quantity of vegetable matter, and has the benefit of a warm aspect and favouring slope."* It has all the advantages, in short, which physical condition and climate can give it, and yet it is unproductive. And why? Because, answers chemical analysis, it is destitute of certain mineral constituents which plants require for their daily food. The physical properties, therefore, are only accessory to the chemical constitution. They bring into favourable circumstances, and thus give free scope to the operation, upon the seeds and roots of plants, of those chemical substances which nature has kindly placed in most of our soils, or by the lessons of daily experience is teaching the skilful labourer in her fields to supply by art.

And yet the study of the physical properties of soils is not without its use, even in a theoretical point of view. It shows both the use of the fundamental admixture of sand, clay, and vegetable matter, of which our soils consist, and for what special end all the mechanical labours of the husbandman are undertaken, and why they are so necessary. Plants must be firmly fixed, therefore the soil must have a certain consistency—their roots must find a ready passage in every direction; therefore the soils must be somewhat loose and open. Except for these purposes, we see little *immediate* use for the sand and alumina which form so much of the substance of soils—till we come to study their physical properties. The siliceous sand is insoluble, and the alumina exists in plants in very minute quantity only, while, during the progress of natural vegetation, the proportion of vegetable matter in the soil actually increases. The *immediate* agency, therefore, of these substances is not chemical but physical.

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* *Bodenkunde*, p. 203.

The alumina of the clays is of immediate use in absorbing and retaining both water and air for the use of the roots—while the vegetable matter is advantageous in reference to the same ends, as well as to the power of absorbing quickly and largely the warmth of the sun's rays. The soil, in short, in reference to vegetation, performs the four following distinct and separate, but each of them important and necessary, functions:—

1°. It upholds and sustains the plant, affording it a sure and safe anchorage.

2°. It absorbs water, air, and heat, to promote its growth.

These are its mechanical and physical functions.

3°. It contains and supplies to the plant both organic and inorganic food as its wants require; and

4°. It is a work-shop in which, by the aid of air and moisture, chemical changes are continually going on; by which changes these several kinds of food are prepared for admission into the living roots.

These are its chemical functions.

All the operations of the husbandman are intended to aid the soil in the performance of one or other of these functions. To the most important of these operations—the methods adopted by the practical farmer for improving the soil—it is my intention, in the following division of these lectures, briefly to direct your attention.

LECTURES

ON

AGRICULTURAL CHEMISTRY

AND

GEOLOGY.

PART III.

ON THE IMPROVEMENT OF THE SOIL BY MECHANICAL MEANS
AND BY MANURES.

BY

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LECTURE XIV.

The physical qualities and chemical constitution of a soil may be changed by art.—Nature of the plants dependent upon that of the soil on which they grow.—Mechanical methods of improving the soil.—Effects produced by draining.—Theory of springs.—Effect of ploughing, subsoiling, deep ploughing and trenching.—Artificial improvement by mixing with clay, sand, or marl.

THE facts detailed in the preceding lecture may be considered as affording sufficient proof that the ability of the farmer to grow this or that crop upon his land, is very much restrained by its natural character and constitution. Each soil establishes upon itself—so to speak—a vegetation suited to its own nature, one that requires most abundantly those substances which actually abound in the soil—and the art of man cannot long change this natural connection between the living plant and the kind of land in which it delights to grow.

But he can change the character of the land itself. He can alter both its physical qualities and its chemical constitution, and thus can fit it for growing other races of plants than those which it naturally bears—or, if he choose, the same races in greater abundance and with increased luxuriance. It is, in fact, in the production of such changes, that nearly all the labour and practical skill of the husbandman—apart from local peculiarities of climate, &c.—is constantly expended. For the attainment of this end he drains, ploughs, subsoil-ploughs, and otherwise works his land. For this end he clays, sands, marls, and manures it. By these and similar operations the land is so changed as to become both able and willing to nourish and ripen those peculiar plants which the agriculturist wishes to raise. On this practical department of the art of culture, the principles explained and illustrated in the preceding parts of these lectures, throw much light. They not only explain the reason why certain practices always succeed in the hands of the intelligent farmer—but why others also occasionally and inevitably fail—they tell him which practices of his neighbours he ought to adopt, and which of them he had better modify or wholly reject,—and they direct him to such new modes of improving his land as are likely to add the most to its permanent productive value.

The operations of the husbandman in producing changes upon the land—are either mechanical or chemical. When he drains, ploughs, and subsoils, he alters chiefly the physical characters of his soil—when he limes and manures it, he alters its chemical constitution. These two classes of operations, therefore, are perfectly distinct. Where a soil contains all that the crops we desire to grow are likely to require, mere mechanical operations may suffice to render it fertile—but where one or more of the inorganic constituents of plants are wanting, draining may prepare the land to benefit by further operations, but will not be alone sufficient to remove its comparative sterility. I shall, therefore, consider in succession these two classes of practical operations :—

1°. *Mechanical methods* of improving the soil, including draining, ploughing, mixing with clay, sand, &c.

2°. *Chemical methods*, including limeing, marling, and the application of vegetable, animal, and mineral manures.

To satisfy you fully, however, in regard to the absolute necessity for such changes, if we would render the land fit to produce any given crop, let me illustrate, by a few brief examples, the intimate relation observed in nature between the kind of soil and the kind of plants that grow upon it.

§ 1. *On the connection between the kind of soil and the kind of plants that grow upon it.*

That a general connection exists between the kind of soil and the kind of plants that grow upon it, is familiar to all practical men. Thus clay soils are generally acknowledged to be best adapted for wheat—loamy soils for barley—sandy loams for oats or barley—such as are more sandy still for oats or rye—and those which are almost pure sand for rye alone of all the corn-bearing crops.

But in a state of nature, we find special differences among the spontaneous produce of the soil, which are more or less readily traceable to its chemical constitution in the spots where the plants are seen to grow. Thus—

1°. On the sandy soils of the sea-shores, and on the salt steppes of Hungary and Russia, the sand-worts, salt-worts, glass-worts, and other salt-loving plants abound. When these lands are inclosed and drained, the excess of the salt is gradually washed out by the rains, or in some countries is removed by reaping the saline plants annually, and burning them for soda (barilla), when wholesome and nutritive grasses take their place; but the white clover and the daisy, and the dandelion must first appear, before, as a general rule, it can be profitably ploughed up and sown with corn.

2°. The dry drifted sands, more or less remote from the sea, produce no such plants. They are distinguished by their own coarse grasses, among which the *elymus arenarius* (upright sea lyme-grass) often, in our latitudes, occupies a conspicuous place. On the downs of North Jutland, it was formerly almost the only plant which the traveller could meet with over an area of many miles.

3°. On ordinary sandy soils leguminous plants are rare, and the herbage often scanty and void of nourishment. With the presence of marl in such soils, the natural growth of leguminous plants increases. The colt's-foot also, and the butter-bur, not only grow naturally where the subsoil is marly, but infest it sometimes to such a degree as to be with great difficulty extirpated. So true is this indication of the nature of the soil, that in the lower valleys of Switzerland these plants are said to indicate to the natives where they may successfully dig for marl.* On calcareous soils, again, or such as abound in lime, the quicken or couch-grass is seldom seen as a weed,† while the poppy, the vetch, and the darnel abound.

4°. So peaty soils, when laid down to grass, slowly select for themselves a peculiar tribe of grasses, especially suited to their own nature, among which the *holcus lanatus* (meadow soft-grass) is remarkably abundant. Alter their constitution by a heavy limeing, and they produce luxuriant green crops and a great bulk of straw, but give a coarse thick-skinned grain, more or less imperfectly filled. Alter them further by a dressing of clay, or keep them in arable culture, and stiffen them with composts, and they will be converted into rich and sound corn-bearing lands.

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* *Prize Essays of the Highland Society*, I., p. 134.

† Sprengel, *Bodenkunde*, p. 201.

5°. In the waters that gush from the sides of lime-stone hills—on the bottoms of ditches that are formed of limestones or marls—and in the springs that have their rise in many trap rocks, the water-cress appears and accompanies the running waters, sometimes for miles on their course. The mare's-tail (*equisetum*), on the other hand, attains its largest size by the marshy banks of rivulets in which not lime but silica is more abundantly present. So the Cornish heath (*erica vagans*) is found only over the serpentine soils of Cornwall, and the red broom rape (*orobanche rubra*)* only on decayed traps in Scotland and Ireland.

These facts all point to the same natural law, that where other circumstances of climate, moisture, &c., are equal, *the natural vegetation—that which grows best on a given spot—is entirely dependent upon the chemical constitution of the soil.*

But both the soil, and the vegetation it willingly nourishes, are seen to undergo slow but natural changes. Lay down a piece of land to grass, and, after a lapse of years, the surface soil—originally, perhaps, of the stiffest clay—is found to have become a rich, light, vegetable mould, bearing a thick sward of nourishing grasses, almost totally different from those which naturally grew upon it when first converted into pasture. So in a wider field, and on a larger scale, the same slow changes are exhibited in the vast natural forests that are known to have long covered extensive tracts in various countries of Europe.

Thus it is a matter of history that Charlemagne hunted in the forest of Gerardmer, then consisting of oak and beech—though now the same forest contains only pines of various species. On the Rhine, between Landau and Kaiserlautern, oak forests, of several centuries old, are seen to be gradually giving way to the beech, while others of oak and beech are yielding to the encroachments of the pine. In the Palatinate, the Scotch fir (*pinus sylvestris*) is also succeeding to the oak. In the Jura, and in the Tyrol, the beech and the pine are seen mutually to replace each other—and the same is seen in many other districts. When the time for a change of crop arrives, the existing trees begin to languish one after another, their branches die, and finally their dry and naked tops are seen surrounded by the luxuriant foliage of other races.* These facts not only show how much the vegetable tribes are dependent upon the chemical nature of the soil—they indicate, likewise, the existence of slow natural changes in the constitution of the soil, which lead necessarily to a change of vegetation also.

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* Hooker's *Flora Scotica*.

We can ourselves, in the case of ancient forests, effect such changes. When in the United States a forest of oak or maple is cut down, one of pine springs up in its place; while on the site of a pine forest, oaks and other broad leaved trees speedily appear.

But if the full time for such changes has not yet come, the new vegetation may be overtaken, and smothered by the original tribes. Thus, when the pine forests of Sweden are burned down, a young growth of birch succeeds, but after a time the pines again appear and usurp their former dominion. The soil remains, still, more propitious to the growth of the latter than of the former kind of tree.

We may, therefore, take a practical lesson from the book of nature. If we wish to have a luxuriant vegetation upon a given spot, we must either select such kinds of seeds to sow upon it as are fitted to the kind of soil, or we must change the nature of the land so as to adapt it to our crop. And, even when we have once prepared it to yield abundant returns of a particular kind, the changes we have produced can only be more or less of a temporary nature. Our care and attention must still be bestowed upon it, that it may be enabled to resist the slow natural causes of alteration, by which it is gradually unfitted to nourish those vegetable tribes which it appears now to delight in maintaining.

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* Le Baron de Mortemart de Boisse, *Voyage dans les Landes*, p. 189.

Let us now turn our attention, therefore, to the methods by which these beneficial changes are to be effected and maintained.

§ 2. *Of draining, and its effects.*

Among the merely mechanical methods by which those changes are to be produced upon the soil, that are to fit it for the better growth of valuable crops, draining is now allowed to hold the first place. That it is an important step in heavy clay lands, and that it must be the *first* step in all cases where water abounds in the surface soil, will be readily conceded; but that it can be beneficial also in situations where the soils are of a sandy nature—where the subsoil is light and porous—or where the inclination of the field appears sufficient to allow a ready escape to the water, does not appear so evident and is not unfrequently, therefore, a matter of considerable doubt and difficulty. It may be useful, then, briefly to state the several effects which in different localities are likely to follow an efficient drainage of the land :—

1°. It carries off all stagnant water, and gives a ready escape to the excess of what falls in rain.

2°. It arrests the ascent of water from beneath, whether by capillary action or by the force of springs —and thus not only preserves the surface soil from undue moisture, but also frees the subsoil from the lingering presence of those noxious substances, which in undrained land so frequently lodge in it and impair the growth of deep-rooted plants.

3°. It allows the water of the rains, instead of merely running over and often injuriously washing the surface, to make its way easily through the soil. And thus, while filtering through, not only does the rain-water impart to the soil those substances useful to vegetation, which, as we have seen,[*] it always contains in greater or less abundance; but it washes out of the upper soil, and when the drains are deep enough, out of the subsoil also, such noxious substances as naturally collect and may have been long accumulating there—rendering it unsound and hurtful to the roots. The latter is one of those benefits which *gradually* follow the draining of land. When once thoroughly effected, it constitutes a most important permanent improvement, and one which can be fully produced by no other available means. It will be permanent, however, only so long as the drains are kept in good condition. The same openness of the soil which enables the rains to wash out those soluble noxious substances, which have been long collecting, permits them to carry off also such as are gradually formed, and thus to keep it in a sound and healthy state; but let this openness be more or less impaired by a neglect of the drainage, and the original state of the land will again gradually return.

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[*] See pages 47, 96, and 240.

4°. This constant descent of water through the soil causes a similar constant descent of fresh air through its pores, from the surface to the depth of the drains. When the rain falls, it enters the soil and more or less completely displaces the air which is contained within its pores. This air either descends to the drains or rises into the atmosphere. When the rain ceases, the water, as it sinks, again leaves the pores of the upper soil open, and fresh air consequently follows. It is in fact sucked in after the water, as the latter gradually passes down to the drains. Thus, where a good drainage exists, not only is the land refreshed by every shower that falls—not only does it derive from the rains those important substances which occasionally, at least, are brought down by them from the atmosphere, and which are in a great measure lost where the waters must flow over the surface—but it is supplied also with renewed accessions of fresh air, which experience has shown to be so valuable in promoting the healthy growth of all our cultivated crops.

5°. But other consequences of great practical importance follow from these immediate effects. When thus readily freed from the constant presence of water, the soil gradually becomes drier, sweeter, looser, and more friable.

The hard lumps of the stiff clay lands more or less disappear. They crumble more freely, offer less resistance to the plough, and are in consequence more easily and more economically worked. These are practical benefits, equivalent to a change of soil, which only the farmer of stubborn clays can adequately appreciate.

6°. With the permanent state of moisture, the *coldness* of many soils also rapidly disappears. The backwardness of the crops in spring, and the lateness of the harvest in autumn, are less frequently complained of—for the drainage in many localities produces effects which are *equivalent to a change of climate.* "In consequence of the drainage which has taken place in the parish of Peterhead, in Aberdeenshire, during the last 20 years, the crops arrive at maturity ten to fourteen days sooner than they formerly did;*" and the same is true to a still greater extent in many other localities.

7°. On stiff clay lands, well adapted for wheat, wet weather in the autumn not unfrequently retards the sowing of winter corn—in undrained lands often completely prevents it—compelling the farmer to change his system of cropping, and to sow some other grain, if the weather permit him, when the spring comes round. An efficient drainage carries off the water so rapidly as to bring the land into a workable state soon after the rain has ceased, and thus, to a certain extent, it rescues the farmer from the fickle dominion of the uncertain seasons.† To the skilful and intelligent farmer, who applies every available means to the successful prosecution of his art, the promise even in our age and country is sure—"that seed-time and harvest shall never fail."

8°. But on lands of every kind this removal of the superfluous water is productive of another practical benefit. In its consequences it is *equivalent to an actual deepening of the soil.*

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* Mr. Gray, in the *Prize Essays of the Highland and Agricultural Society*, II. p. 171. This opinion was given in 1830, since which time many other extensive improvements have been made in that part of the island.

† "Formerly," says Mr. Wilson, of Cumledge, in his account of the draining of a farm in Berwickshire, "this part of the farm was so wet, that—though better adapted for wheat than any other crop—the season for sowing was frequently lost, and after an expensive fallowing and limeing, it was sown with oats in spring, of which it always produced very poor crops. It is now so dry as to grow very good crops of turnip or rape, and, except in two instances, I have always sown my wheat in capital order."—*Ibid.* I, p. 243.

When land, on which the surface water is in the habit of resting, becomes dry enough to admit the labours of the husbandman, it is still found to be wet beneath, and the waters, even in dry seasons, not unfrequently remain where the roots of the crops would otherwise be inclined to come. Or, if the surface soil permit a ready passage to the rains, and the waters linger only in the moist subsoil, still—though the farmer may not be delayed in his labours—the subsoil repels the approach of the roots of his grain, and compels them to seek their nourishment from the surface soil only. But remove the waters, and the soil becomes dry to a greater depth. The air penetrates and diffuses itself wherever the waters have been. The roots now freely and safely descend into the almost virgin soil beneath. And not only have they a larger space through which to send out their fibres in search of food, but in this hitherto ungenial soil they find a store of substances—but sparingly present, it may be, in the soil above—which the long-continued washing of the rains, or the demands of frequent crops, may have removed, but which may have been all the while accumulating in the subsoil, into which the roots of cultivated plants could rarely with safety descend. It is not wonderful, then, that the economical effects of draining should be found by practical men to be not only a diminution in the cost of cultivation, but a considerably augmented produce also both in corn and grass; or that this increased produce should alone be found sufficient to repay the entire cost of thorough-draining in two or three years.

An obvious practical suggestion arises out of the knowledge of this fact. The deeper the drains, *provided the water have still a ready escape*, the greater the depth of soil which is rendered available for the purposes of vegetable nutrition. Deep rooted plants, such as lucerne, often fail, even in moderately deep soils, because an excess of water or the presence of some noxious ingredient which deep drains would remove, prevents their natural descent in search of food. Even plants, which, like that of wheat or clover, do not usually send down their roots so far, will yet, where the subsoil is sound and dry, extend their fibres for three or more feet in depth, in quest of more abundant nourishment.

Not only, then, do deep drains permit the use of the subsoil plough without the chance of injury,—not only are they less liable to be choked up by the accumulated roots of plants which naturally make their way into them in search of water,—but they also increase the value and permanent fertility of the land, by increasing its available depth. In other words, that kind of drainage which is most efficiently performed, with a regard to the greatest number of contingencies, will not only be the most permanent, but will also be followed by the greatest number of *economical advantages.*

9°. Nor do the immediate and practical benefits of draining end with the attainment of these beneficial results. It is not till the land is rendered dry that the skilful and enterprising farmer has a fair field on which to expend his exertions. In wet soils, bones, wood-ashes, rape-dust, nitrate of soda, and other artificial manures are almost thrown away. Even lime exhibits but one-half of its fertilizing virtue, where water is allowed to stagnate in the soil. Give him dry fields to work upon, and the well instructed agriculturist can bring all the resources, as well of modern science as of old experience, to bear upon them, with a fair chance of success. The disappointments which the holder of undrained lands so often meets with, *he* will less frequently experience. An adequate return will generally be obtained for his expenditure in manuring and otherwise improving his soil, and he will thus be encouraged to proceed in devoting his capital to the permanent amelioration of his farm—not less for his own than for his landlord's benefit.

Viewed in this light, draining is only the first of a long series of improvements, or rather it is a necessary preparative to the numerous improvements of which the soil of our islands is susceptible—which improvements it would be a waste of money to attempt, until an efficient system of drainage is established. And when we consider how great a national benefit this mere preparatory measure alone is fitted *directly* to confer upon the country, you will agree with me in thinking that every good citizen ought to exercise his influence in endeavouring, in his own district, more or less rapidly to promote it. It has been calculated that the drainage of those lands only, which are at present in arable culture, (10 millions of acres,) would at once increase their produce by 10 millions of quarters of the various kinds of grain now grown upon them;—and that a similar drainage of the uncultivated lands (15 millions of acres) would yield a further increased produce of *twice* as much more. This increase of 30 millions of quarters is equal to nearly one-half of our present consumption[*] of *all* kinds of grain—so that were it possible to effect at once this general drainage, a large superfluity of corn would be raised from the British soil.

This general drainage, however, cannot possibly be effected in any given time. The individual resources of the land-owners are not sufficient to meet the expense,[†] and such calculations as the above are useful, mainly, in stimulating the exertions of those who have capital to spare, or such an excess of income as can permit them to invest an annual portion permanently[‡] in the soil.

10°. He who drains and thus improves his own land, confers a benefit upon his neighbours also. In the vicinity of wet and boggy lands the hopes of the industrious farmer are often disappointed. Mists are frequent and rains more abundant on the edges of the moor, and mill-dews retard the maturity, and often seriously injure the crops. Of undrained land, in general, the same is true to a less extent, and the presence of one unimproved property in the centre of an enterprising district, may long withhold from the adjoining farms that full measure of benefit which the money and skill expended upon them would in other circumstances have immediately secured.

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[*] 65 millions of quarters. See an excellent paper on this subject in the *Quarterly Agricultural Journal*, xii. p. 505, by Mr. Dudgeon, of Spyelaw, in Roxburghshire, a county in which the practical benefits of draining have been extensively experienced and are therefore well understood.

[†] To drain 25 millions of acres, at £6 an acre, would cost 150 millions sterling, a sum equal, probably, to the whole capital at present invested in *farming* the land.

[‡] By an efficient drainage, the soil is *permanently benefitted*, but it is not so clear that the money it costs is *permanently invested* or buried in the soil. If the cost be repaid by the increase of produce in three years, the money is not invested, it is only *lent* for this period to the soil. "I drain so many acres every year," said the holder of a large Berwickshire farm to me, "and I find myself always repaid by the end of the third season. If I have spare capital enough, therefore, to go on for three years, I can gradually drain any extent of land, by the repeated use of the same sum of money."

So true is it in regard to every new exercise of human skill and in every walk of life, that we are all mutually dependent, every one upon every other; and that the kindly co-operation of all can alone secure that ample return of good, which the culture either of the dead earth or of the living intellect appears willing, and we may hope is ultimately destined, to confer upon our entire race.

11°. I would not here willingly neglect to call your attention to a higher benefit still, which the skilful drainage of an extensive district is fitted to confer upon its whole population. Not only is this drainage equivalent, as above stated, to a change of climate in reference to the growth and ripening of plants, but it is so also in reference to the *general health* of the people and to the number and kind of the diseases to which they are observed to be exposed.

I may quote in illustration of this fact the interesting observations of Dr. Wilson on the comparative state of health of the labouring population in the district of Kelso, during the last two periods of ten years. In his excellent paper on this subject, in the *Quarterly Journal of Agriculture*,* he has shown that fever and ague, which formed nearly one-half of all the diseases of the population during the former ten years, have almost wholly disappeared during the latter ten, in consequence of the general extension of an efficient drainage throughout the country; while, at the same time, the fatality of disease, or the comparative number of deaths from every hundred cases of serious ailment, has diminished in the proportion of 4·6 to 2·59. Such beneficial results, though not immediately sought for by the practical farmer, yet are the inevitable consequence of his successful exertions. Apart, therefore, from mere considerations of pecuniary profit, a desire to promote the general comfort and happiness of the entire inhabitants of a district may fairly influence the possessors of land to promote this method of ameliorating the soil; while the whole people, on the other hand, of whatever class, ought "gratefully to acknowledge the value of those improvements which at once render our homes more salubrious and our fields more fruitful."

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* Volume xii. p. 317.

The practical benefits of draining, therefore, may be stated generally as follows:—

A. It is equivalent not only to a change of soil but also to a change of climate, both in reference to the growth of plants and to the health of the population.

B. It is equivalent also to a deepening of the soil, both by removing the water and by allowing those noxious ingredients to be washed out of the subsoil which had previously prevented the roots from descending.

C. It is a necessary preparation to the many other means of improvement which may be applied to the land.

You will now be able to perceive in what way it is possible that even light and sandy soils, or such as lie on a sloping surface, may be greatly benefitted by draining. Where no open outlet exists under a loamy or sandy surface soil, any noxious matters that either sink from above, or ooze up from beneath, will long remain in the subsoil, and render it more or less unwholesome to valuable cultivated plants. But let such an outlet be made by the establishment of drains, and that which rises from beneath will be arrested, while that which descends from above will escape. The rain-waters passing through will wash the whole soil also as deep as the bottom of the drains, and the atmospheric air will accompany or follow them.

The same remarks apply to lands which possess so great a natural inclination as to allow the surface water readily to flow away. Such a sloping surface does not necessarily dry the subsoil, free it from noxious substances, or permit the constant access of the air. Small feeders of water occasionally make their way near to the surface, and linger long in the subsoil before they make their escape. This is in itself an evil, but when such springs are impregnated with iron the evil is greatly augmented, and from such a cause alone a more or less perfect barrenness not unfrequently ensues. To bring such lands by degrees to a sound and healthy state, a mere outlet beneath is often alone sufficient.

It is to this lingering of unwholesome waters beneath, that the origin of many of our moor-lands, especially on higher grounds, is in a great measure to be attributed. A calcareous or a ferruginous spring sends up its waters into the subsoil. The slow access of air from above, or it may be the escape of air from the water itself, causes a more or less ochrey deposit,* which adheres to and gradually cements the stones or earthy particles, among which the water is lodged. Thus a layer of solid stone is gradually formed—the *moor-land pan* of many districts—which neither allows the roots of plants to descend nor the surface water to escape. Hopeless barrenness, therefore, slowly ensues. Coarse grasses, mosses, and heath, grow and accumulate upon soils not *originally* inclined to nourish them, and by which a better herbage had previously been long sustained. Of such lands many tracts have been reclaimed by breaking up this moor-land pavement, but such an improvement, unless preceded by a skilful drainage, can only be temporary. The same natural process will again begin, and the same result will follow, unless an outlet be provided for the waters from which the petrifying deposit proceeds.

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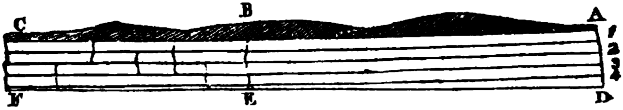
* If the water contain *sulphate* of iron, the air from above will impart to its iron an additional quantity of oxygen, and cause a portion of it to fall in the state of *peroxide*. If the iron or lime be present in the state of *bicarbonate*, the escape of carbonic acid from the water will cause a deposit of *carbonate* of iron or of lime. Any of these deposits will cement the earthy or stony particles together. Iron, however, is sometimes held in solution by an organic acid (*crenic*), which becomes insoluble, and falls along with the iron when the latter has absorbed more oxygen from the atmosphere.

It ought to be mentioned, however, that where a ready passage and escape for the water is provided by an efficient drainage, and especially in light and porous soils, the saline and other soluble substances they contain will be liable, in periods of heavy rain, to be more or less completely washed out and carried off by the water that trickles through them. While, therefore, the establishment of drains on *all* soils may adapt and prepare them for further improvements, and may make them more grateful for every labour or attention that may be bestowed upon them—yet after drainage they must be more liberally dealt with than before, if the increased fertility they at first exhibit is to be permanently maintained or increased.

§ 3. *Of the theory of Springs.*

In the general drainage of the land a double object is sought to be attained. In very rainy districts, the first wish of the farmer is to carry off the surface water from his fields—but where less rain falls, that which ascends from beneath in springs, attracts at least an equal share of the husbandman's regard. In draining, with a view to the removal of this latter source of superfluous moisture, a knowledge of the true theory of springs, as indicated by an examination of certain geological phenomena, is of the greatest possible service to the practical man, in pointing out the sources from which the water that injures his land proceeds, as well as the lines along which it may be most efficiently and most economically carried off.

1°. The rain which falls on the surface of an extensive tract of country partly escapes into the rivers, and partly sinks into the earth. This latter portion descends through the covering of soil and other loose materials till it reaches the rocks on which they rest. If these rocks are porous, like many sand-stones, or are traversed by cracks and vertical fissures, as many sand-stones and lime-stones are, it descends through them also till it reaches a bed, such as one of indurated clay, so close and compact as to resist its further passage. By this *impervious* bed the water is arrested, and is, therefore, compelled to spread itself laterally, and gradually to accumulate in the beds that lie above it. Thus, if the outline from A to C in the annexed diagram represent the surface of an undulating country, in



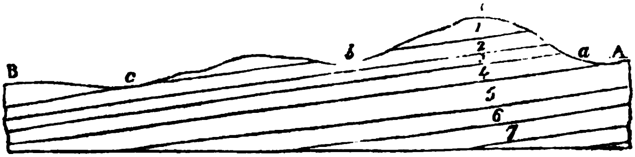
which the subjacent rocks (1, 2, 3, 4) are covered by a considerable thickness of loose materials, the rain which falls from A to B will sink more or less rapidly to the bed (1), and, if this be impermeable to water, will rest there, or will slowly drain off in the direction of B and C along the inclined surface of the rock. But if (1) be porous, it will sink through it to the surface of the bed (2), and through this also, if permeable, to (3) or (4), until it reach a stratum through which it cannot pass. On the surface of this latter bed, or among the rocks above it, the water will accumulate until, flowing downwards towards C, it is enabled either to sink among the deeper rocks, or to make its escape again to the surface.

But if the rocks beneath, as is shown in the same diagram from E to F, be traversed by vertical fissures passing through two or more, or, like the one represented from B to E, through a great number of beds, the water that falls on the surface will readily find a passage downwards to a considerable depth, and to the same cracks the water that lodges among the unfissured rocks from D to E will also gradually make its way.

The practical effects of these several conditions on the drainage of a country are very obvious. If the stratum (1) be impervious to water, the surface from A to B may be full of water, and may urgently demand the introduction of drains, whereas if (1) and (2) be porous, the surface water will gradually sink, and the apparent necessity for artificial drainage will become much less striking. On the other hand, where the rocks are filled with frequent cracks, as from B to C, the surface water may descend and disappear so rapidly, as to render useless the sinking of

wells—and, as in dry summers, greatly to retard the progress of the crops, or even seriously to injure the produce of the harvest. In such a fissured state are the magnesian lime-stone rocks in some parts of the county of Durham—and such is the consequent scarcity of water, on some farms, that when, in long droughts, the supply preserved in artificial tanks begins to fail, the cattle must be driven to water, sometimes for miles, to the nearest living brook.

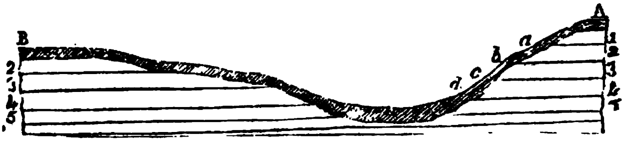
2°. But water often finds its way to great depths without passing through the superior strata, and even where they are absolutely impervious to the rains that fall upon them.



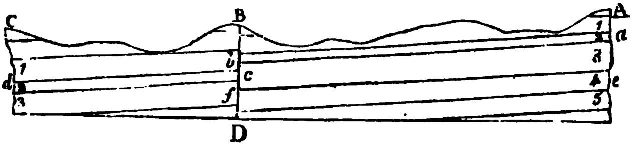
Thus along the country from A to B, and especially towards A, the surface soil rests upon the upper edges of the strata. Suppose now the beds 1, 2, 3, to be impervious to water, the rain that falls wherever these rocks lie immediately beneath the surface will either remain stagnant, or will flow off by some natural drainage. Thus from the highest point C in the above diagram, the water will descend on either hand towards *a* and *b*. At *b* it may remain stagnant, for it cannot descend through the bed (2), which forms the bottom of the valley, and the same is true of the hollow *c*, in which other portions of the water will rest. All this tract of country, therefore, will be more or less cold, wet, and consequently unproductive. But let the bed (4), the edge (or *outcrop*) of which forms the surface at *a*, be porous or permeable, then the water which falls upon that spot or which descends from the higher grounds about C and A, will readily sink and drain off, descending from *a* towards *d* along the inclined bed till it finds an outlet in the latter direction.

Thus it may readily happen that a naturally dry and fertile valley, as at *a*, may exist at no great distance from others, *b* and *c*, which are marshy and insalubrious, and in which artificial drainage alone can develope the agricultural capabilities of the soil. It appears also that, though in any district the rocks which lie immediately beneath the surface may contain no water, and may allow none to pass through them, yet that other beds, perhaps at a great depth beneath, may contain much. It is, in fact, this accumulation of water beneath impervious beds that gives rise to many natural springs, and enables us by artificial wells to bring water to the surface—often where the land would otherwise be wholly uninhabitable.

3°. Thus in undulating countries, where hill-sides frequently present themselves, or vallies are scooped out among the rocks, as in the following wood-cut, the water that has fallen over the high grounds towards A, and has entered as above described, or has sunk down to the several strata 1, 2, 3, &c., will find a ready outlet along the slope of the valley, and will give rise to springs at *a*, *b*, *c*, or *d*, according as the water has lodged in the one or the other of these beds. These springs will fill the surface soil with water, which will also descend into the bottom of the valley, and, if no sufficient outlet be provided for it, will, according to its quantity, give rise to a lake, a bog, or a morass. On the slope towards B, the same springs are not to be expected, since the rains which sink through the surface on this side of the valley, and lodge in the porous rocks beneath, will, by the inclination of the beds, be drawn off in the opposite direction, till a second valley or some other available outlet present itself for their escape. This explains why the land on one side of a valley or of a hill is often much drier than on the other, and why, even in the absence of the improver's skill, an apparently more fertile soil may exist, and better crops be reaped.



4°. Again, such an outlet for the waters that rest among inclined strata is not unfrequently afforded, without the intervention of vallies, and even in level or hilly countries, by the existence of *slips* or *faults* in the rocks beneath. Such a slip or shifting of the beds is represented in the following diagram, in which B D is a crack, along which



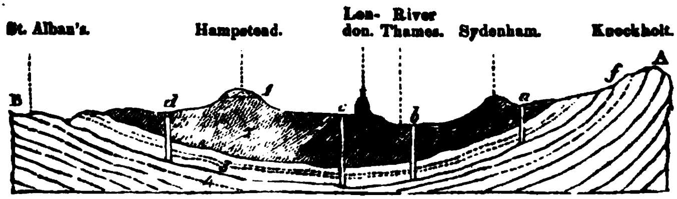
the strata from B to C appear to have *slipped* downwards, so that the thin bed, (2) for example, which terminates at *b* on the one side of the crack, begins again at a lower level *c* on the other side, and so with the other beds that lie above and below it. None of them is exactly continuous on the opposite sides of the slip. From such cracks or faults in the beds, springs of water often rise to the surface, even on hill-tops, as at B, and they may be thus thrown or forced out from either of two causes—

1. These slips are often of considerable width, and are usually found to be filled with impervious clay. This is the case at least among the coal-measures, which have been the most extensively explored. The effect of this wall of clay is to dam back at B D the water which descends along the inclined beds towards C from the country beyond A, and thus to arrest its further progress. But the pressure of the water behind forces that which has reached the fault B D to seek a way upwards, and, as spaces not unfrequently exist between the wall of clay and the rocks between which it stands, the water finds a more or less ready outlet at the surface B, and either gushes forth as a living and welcome spring, or oozes out unseen among the soil, rendering it cold, wet, and unproductive. Thus from *b* the water accumulated in the bed (2) may rise to the surface, or from *f* that which exists in (4), or from any other bed in which water exists, and from almost any depth.

2. But even where no such wall of clay exists, the waters may still find their way to the surface along lines of

fault, and from great depths. Thus, suppose the thin bed (2) to be full of water, and that it is covered by an impervious bed (1), then the water which tends downwards from *a* to *b* will be arrested at the fault, and dammed back by the impervious extremity of (1) against which it now rests. If an outlet can be found, it will therefore rise towards the surface. And as the rocks incline upwards in the direction of A, the pressure from behind may easily cause the water to ascend to the summit of the hill at B, and to gush out in a more or less copious spring.

5°. Where no natural outlets of the kind above described exist in a district, there may be a great scarcity of water on the surface, while abundance, as we have already seen (2°), may exist in the rocks beneath, ready and willing to rise if a passage be opened for it. Such is the case with the site of the City of London, represented below :—



SECTION ACROSS THE LONDON BASIN FROM ST. ALBAN'S TO KNOCKHOLT.
(*Buckland's Bridgewater Treatise, plate 69.*)

1. Marine Sand.
2. London Clay (almost impermeable.)
3. Plastic Clay and Sand.
4. Chalk, both full of water.

The rain-water which falls between *a* and A on the one hand, and upon the plastic clay and chalk between *d* and B on the other, sinks into these two beds and rests in them till it finds an escape. It cannot rise through the great thickness of impervious clay on which London and its neighborhood stands, unless where wells are sunk, as above represented at *a*, *b*, *c*, *d*, either into the plastic clay (3), or into the chalk (4), when the water ascends copiously till it reaches the general level of the country about St. Alban's, the lowest part of the basin where the permeable beds form the surface. Hence, in the vale of the Thames at *b*, it rises above the surface, and forms a living spring, while at other places, as at *a*, *c*, *d*, it has still to be pumped up from a greater or less depth.* It is the existence of water beneath the surface where the soils rest on impermeable beds, and the known tendency of these waters to rise when a boring is sunk to them, that have given rise to the establishment of *Artesian*† wells, so frequently executed, and with so much success, in recent times. There is probably no geological fact that promises hereafter to be of more practical value to mankind, when good government and the arts of peace shall obtain a permanent resting-place in those countries where, without irrigation, the soil remains hopelessly barren. Wherever a living spring bursts out in the sands of Arabia, in the African deserts, or in the parched plains of South America, an island of perennial verdure delights the eye of the weary traveller, and wherever in such countries the labour of man has been expended in digging wells, and in raising water from them for artificial irrigation, the same beauty and fertility always appear. It has recently been found that the Oases of Thebes and Garba, in Upper Egypt, where the blown sands now hold a scarcely disputed dominion, are almost *riddled* with wells sunk by the ancient Egyptians, but for the greater part long since filled up. The re-opening of such wells might restore to these regions their long lost fertility, as the sinking of new ones by our easier and more economical methods might reclaim many other wide tracts, and convert them to the use of man. In contemplating what man may do, when his angry passions and his prejudices do not interfere with the exercise of his natural dominion over dead matter, it is not unreasonable to hope that, guided by such indications of natural science, human industry may hereafter, by slow degrees, re-establish its power in long deserted regions of country, spreading abundance over the broad wilderness, staying the Arab's wandering foot, and fixing his household in a permanent and plenteous home.

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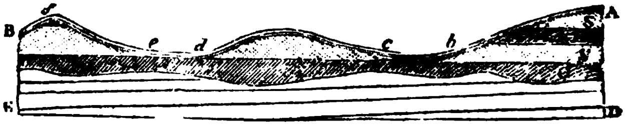
* In January, 1840, there were stated to be in the London clay upwards of 200 such wells, of which 174 were in London, and of which latter 30 taken together were known to yield 30 millions of gallons weekly. This number of wells has since been increased, and is still increasing. The borings are generally carried down into the chalk, because the water which ascends from the plastic clay has been found to bring with it much sand, which both obstructs the pipes and is injurious to the pumps.

† So called from the district of *Artois*, in France, in which it was formerly supposed that such borings had been longest or most extensively practised.

6°. It not unfrequently happens that alternate layers of sand and clay overspread the rocks of a country, and act in arresting or in *throwing out* the surface water in the same manner as the solid strata beneath. Thus under the surface A B here represented, alternate layers of sand and clay overspread the inclined beds of rock, and alone affect not only the quality but the state of dryness also of the soil.

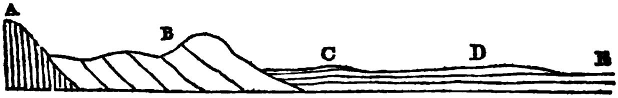


C clay. S sand.

The rain which falls on the upper bed of sand will sink no further than the first bed of clay, and will appear as a spring, or will form a wet band along the side of the hill, at *a*. That which falls or exists in the second bed of sand will in like manner come to day at *b*, *c*, and *d*, *e*, filling the two vallies more or less with water, and forming wet tracts of country resting upon a lower bed of impervious clay.

In endeavouring to form a satisfactory opinion as to the best mode of draining a piece of land, it is of great importance to be able to determine not only the immediate *natural source* of the water we are desirous to remove, but also the probable *quantity* it may be necessary to carry off, and the *permanence* of the supply. It is well known, for example, that in many spots, when the accumulated waters are once carried off there remains only a small, and probably intermitting supply, for which an outlet is afterwards to be left and kept open; while in other localities a constant stream of water is seen to pass along the drains. In connection with this point it is of consequence to make out whether the water is thrown out by surface clays, as in this latter diagram, or flows from among the solid rocks at a greater or less depth—as shown in the preceding wood-cuts. That which is thrown out by beds of clay is in most cases derived only from the rains that fall, and is, therefore, liable to intermit, to cease altogether, or to become more copious, according as the season is dry or otherwise; while that which escapes from a bed of rock, being independent of the seasons, will seldom vary in quantity. Thus it happens that where surface water only stagnates in the soil of a district, a warm, dry, and long continued summer may cause it to yield a crop of unusual excellence, while other soils fed by springs from beneath may, even in such seasons, still retain moisture enough to render them unfit to rear and ripen a profitable crop of corn.

7°. There remains one other interesting principle connected with this subject, which I must briefly explain to you. Let C and D in the accompanying wood-cut be two impervious beds through which the water finds no escape, and from which the rains pass off only by the natural inclination of the ground, and let E be a porous bed from which the water finds a ready escape somewhere towards the right. Then if a boring be sunk through C and D in any part of this tract of country, the water will descend, and will be absorbed by the bed E. Such dry, porous, or absorbent beds exist in many localities, and the skilful drainer may occasionally avail himself of their aid in easily and effectually freeing land from water, which could not without great cost be permanently drained by any other method. Where water collects on the surface resting upon chalk, or upon the loose sands beneath it, this method of boring is frequently had recourse to in some of our southern counties. One danger, however, is to be guarded against in trying this method, that the bore-rod, namely, may enter a bed which is full of water, and from which as in Artesian wells, it may readily, and in considerable quantity, ascend. Such a boring it is obvious would only add



to the evil, and might render necessary a larger outlay in establishing an efficient system of drainage by the ordinary method, than would otherwise have been required.[*]

I do not enter into any further details in regard to the application of these principles to the *practice* of draining, being satisfied that when you have once mastered the principles themselves, the applications will readily suggest themselves to your own minds when circumstances require it.

§ 4. *Of ploughing and subsoiling.*

I. *Ploughing.*—Apart from the obvious effect of ploughing the land, in destroying weeds and insects, the immediate advantage sought for by the farmer is the reduction of his soil to a state of minute division. In this state it is not only more pervious to the roots of his corn, but it also gives a more ready admission to the air and to water.

Of the good effects produced by the easy descent and escape of water from the surface, I have already spoken (p. 6), but the permeability of the soil to air is no less useful in developing its natural powers of production.

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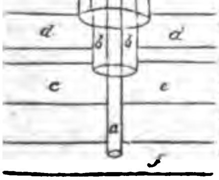
[*] It sometimes happens that in sinking an old well deeper for the purpose of obtaining a better supply of water, the original springs disappear altogether. This is owing to the occurrence at this greater depth, of an *absorbent* bed, in which the water disappears. By descending still further, a second supply of water may often be found, but which will naturally ascend no further than the absorbent bed, by which the whole supply will be drunk up, if not prevented by the insertion of a metal pipe. Advantage is sometimes taken of the known existence of such absorbent strata, not only for the purposes of draining, but also for removing waste water of various kinds. An interesting example of such application is to be seen at St. Denis, in the Place aux Gueldres, where the water from the bed *f* at the depth of 200 feet ascends through the inner tube *a*—from another bed *e*, at 160 feet, through the tube *b*, while between it and the outermost tube, through the space *c*, it is sent down again after it has been employed in washing the square, and disappears in the absorbent stratum *d*.



How important the presence of the air is both to the maintenance of animal and to the support of vegetable life, we have had frequent occasion to observe. By its oxygen the breathing of animals is sustained, and by its carbonic acid the living plant is fed. On the earthy particles, of which the soil consists also, the influence of these gaseous substances, though not so visible and striking, is of almost equal consequence in the economy of nature. Among other immediate benefits derived from the free access of air into the soil, we may enumerate the following :—

1°. The presence of oxygen in the soil is necessary to the healthy germination of all seeds (p. 195), and it is chiefly because they are placed beyond its reach, that those of many plants remain buried for years without signs of life, though they freely sprout when again brought to the surface and exposed to the air. We have also seen reason to believe (p. 109), that the roots of living plants require a supply of oxygen in order that they may be maintained in a healthy condition. Such a supply can only be obtained where the soil is sufficiently open to permit the free circulation of the air among its pores.

2°. In the presence of air the decomposition of the vegetable matter of the soil proceeds more rapidly—it is more speedily resolved into those simpler forms of matter, carbonic acid and water chiefly (p. 228), which are fitted to minister to the growth of new vegetable races. In the absence of the air also, not only does this decomposition proceed more slowly, but the substances immediately produced by it are frequently unwholesome to the plant, and therefore fitted to injure, or materially to retard, its growth.

3°. When the oxygen of the air is more or less excluded, the vegetable matter of the soil takes this element from such of the earthy substances as it is capable of decomposing, and reduces them to a lower state of oxidation. Thus it converts the red or *per*-oxide of iron into the *prot*-oxide (p. 311), and it acts in a similar manner upon the oxides of manganese (p. 315.) It also takes their oxygen from the sulphates (as from gypsum), and converts them into sulphurets. These lower oxides of iron and manganese are injurious to vegetation, and it is one of the beneficial purposes served by turning up the soil in ploughing, or by otherwise loosening it so as to allow the free admission of atmospheric air, that the natural production of these oxides is either in a great measure prevented, or that when produced they speedily become harmless again by the absorption of an additional dose of oxygen.

4°. Further, there are few soils which do not contain, in some quantity, fragments of one or other of those compound mineral substances of which, in a previous lecture (xii., p. 374), we have seen the crystalline rocks to consist—of hornblende, of mica, of felspar, &c., in a decomposing state. From these minerals, as they decompose, the soil, and therefore the plants that grow in it, derive new supplies of several of those inorganic substances which are necessary to the healthy nourishment of cultivated crops. The continued decomposition of these mineral fragments is aided by the access of air, and near its surface, in an especial manner, by the carbonic acid which the air contains. A state of porosity therefore, or a frequent exposure to the air, is favourable to the growth of the plant, by presenting to its roots a larger abundance not only of organic but also of inorganic food.

5°. Again, that production of ammonia and of nitric acid in the soil, to which I drew your especial attention on a former occasion (pp. 236 and 241), as apparently of so much consequence to vegetable life, takes place more rapidly, and in larger quantity, the more frequently the land is turned by the plough, broken by the clod-crusher, or stirred up by the harrow. Whatever amount of either of these compounds, also, the surface soil is capable of extracting from the atmosphere, the entire quantity thus absorbed will evidently be greater, and its distribution more uniform, the more completely the *whole* soil has been exposed to its influence. It is for this, among other reasons, that, as every farmer knows, the better he can plough and pulverize his land, the more abundant in general are the crops he is likely to reap.

6°. Nor lastly, though in great part a mechanical benefit, is it one of little moment that when thus every where pervious to the air, the roots also can penetrate the soil in every direction. None of the food around them is shut up from the approach of their numerous fibres, nor are they prevented, by the presence of noxious substances, from throwing out branches in every direction. A deep soil is not absolutely necessary for the production of valuable crops. A well-pulverized and mellow soil, to which the air and the roots have every where ready access, will, though shallow, less frequently disappoint the hopes of the husbandman,—than were a greater depth prevails, less permeable to the air, and therefore less wholesome to the growing roots.

II. *Subsoil ploughing.*—And yet, as a general rule, it cannot be denied that a deep soil is greatly superior in value to a shallow soil of the same nature. It is so both to the owner and to the occupier, though in too many cases the available qualities of deep soils have hitherto been more or less overlooked and neglected.

The general theoretical principle on this subject—that the deeper the soil the longer it may be cropped without the risk of exhaustion; and the greater the variety of crops, deep as well as shallow-rooted, which may be grown upon it—is so reasonable in itself, as to command a ready acquiescence. But a soil is virtually shallow where a few inches of porous earth, often turned by the plough, rest upon a subsoil, hard, stiff, and almost impervious,—and the practical farmer will rarely be willing to allow the depth of the latter to influence his opinion in regard to the general value of the land. And in this he is so far correct, that a subsoil must be dried, opened up, mellowed by the air, and rendered at once pervious and wholesome to the roots of plants, before it can be made available for the growth of corn. This may be effected, *after draining*, by the use of the subsoil plough, an instrument at present, I believe, unequalled for giving a real, practical, and money-value to stiff and hitherto almost worthless clayey subsoils. It is an auxiliary both to the surface plough and to the drain, and the source of its efficacy will appear from the following considerations:—

1°. The surface plough turns over and loosens the soil to the depth of 6 to 10 inches—the subsoil plough tears open and loosens it to a further depth of 8 or 10 inches. Thus the water obtains a more easy descent, and the air penetrates, and the roots more readily make their way among the particles of the under-soil. So far it is an auxiliary to the common plough, and assists it in aerating and mellowing the soil.

2°. But though it opens up the soil for a time to a greater depth, the subsoil plough will in most cases afford no permanent cure for the deficiencies of the subsoil, *if unaided by the drain*. If the soil rest upon an indurated substratum—upon a calcareous or ochrey *pan*—this plough may tear it up, may thus allow the surface water to sink, and may greatly benefit the land; but the same petrifying action will again recur, and the benefit of the subsoiling will slowly disappear. Or, if the subsoil contain some noxious ingredients, such as salts of iron, which the admission of air is fitted to render harmless, then the use of this plough may afford a partial amelioration. But in this case, also, the effect will be only temporary; since the source of the evil has not been removed, the same noxious compounds will again be naturally produced; or will again, in fresh supplies, be conveyed into the soil by springs. Or, if the subsoil be a stiff clay, containing no noxious ingredient, it may be cut, or for the time torn asunder, but scarcely will the plough have passed over it till the particles will be again cemented together, and probably, by the end of a single season at the furthest, the under-soil may be as solid and impermeable as ever.

It is as the follower of the drain, therefore, in the course of improvement, that the subsoil plough finds its most beneficial and most economical use. After land has been drained, the water may still too slowly pass away, or the air may have too imperfect an entrance into the subsoil from which the drains have removed the water. In the former case, the subsoil plough must be employed, in order that the drains may become fully efficient; in the latter, that the under-layers may be opened up to all the beneficial influences which the atmosphere is fitted to exert upon them. In this respect it is an auxiliary to the drain. But as the full effect which the subsoil plough is capable of producing upon stiff and clayey subsoils, can only be obtained after they have been brought to such a state of dryness that the sides of the cut or tear, which the plough has made, will not again readily cohere, it is of importance that the drains should be allowed a considerable time to operate before the use of this plough is attempted. The expense of the process is comparatively great, and this expense will be in a great measure thrown away upon clay lands, which are undrained, or from which the water, either through defective draining, or from the want of sufficient time, has not been able fully to flow away. There are few kinds of clay land on which the judicious use of this valuable instrument will not prove both actually and *economically* useful, though from the neglect of the above necessary precaution, it has been found to fail in the hands of some. Such failures, however, do not justify us in ascribing to some fancied defect in the instrument, or in the theory upon which its use is recommended, what necessarily arose, and could have been predicted, from our own neglect of an indispensable preliminary observation. The sanguine anticipations of its inventor, Mr. Smith, of Deanston, may not be fully realized, yet the value of the subsoil plough itself, and the benefits it is fitted to confer, when rightly used, appear to me to be both theoretically and practically established.

§ 5. *Of deep-ploughing and trenching.*

Deep-ploughing and trenching differ from ordinary and subsoil ploughing in this,—that their special object is to bring to the surface and to mix with the upper-soil a portion of that which has lain long at a considerable depth, and has been more or less undisturbed.

The benefit of such an admixture of fresh soil is in many localities undoubted, while in others the practical farmer is decidedly opposed to it. On what principle does its beneficial action depend, and in which circumstances is it likely to be attended with disadvantage?

1°. It is known that when a heavy shower of rain falls it sinks into the soil, and carries down with it such readily soluble substances as it meets with on the surface. But other substances also, which are more sparingly soluble, slowly and gradually find their way into the subsoil, and there more or less permanently remain. Among these may be reckoned gypsum, and especially those silicates of potash and soda already spoken of (p. 303), as apparently so useful to corn-growing plants. Such substances as these naturally accumulate beyond the reach of the ordinary plough. Insoluble substances likewise slowly sink. This is well known to be the case with lime, when laid upon or ploughed into the land. So it is with clay, when mixed with a surface soil of sand or peat. They all descend till they get beyond the reach of the common plough—and more rapidly it is said (in Lincolnshire) when the land is laid down to grass than when they are constantly brought to the surface again in arable culture. Thus it happens that after the surface soil becomes exhausted of one or other of those inorganic compounds which the crops require, an ample supply of it may be still present in the subsoil, though, until turned up, unavailable for the promotion of vegetable growth.

There can be little question, I think, that the greater success which attends the introduction of new implements in the hands of better instructed men, upon farms long held in arable culture, is to be ascribed in part to this cause. One tenant, during a long lease, has been in the habit of ploughing to a depth of three, or at most, perhaps, of four inches—and from this surface the crops he has planted have derived their chief supplies of inorganic food. He has limed his land in the customary manner, and has laid upon it all the manure he could raise, but his crops have been usually indifferent, and he considers the land of comparatively little value. But another tenant comes, and with better implements turns up the land to a depth of 7 or 8 inches. He thus brings up to the surface the lime and the accumulated manures which have *naturally* sunk, and which his predecessor had permitted year after year to bury themselves in his subsoil. He thus has a new, often a rich, and almost always a virgin soil to work upon

—one which from being long buried, may require a winter's exposure and mellowing in the air, but which in most cases is sure to repay him for any extra cost. The *deep* ploughing which descends to 14 inches, or the trenching which brings up a new soil from the depth of 20 or 30 inches, is only an extension of the same practice. It is justified and recommended upon precisely the same principle. It not only brings a new soil, containing ample nourishment, to the immediate roots of plants, but it affords them also a deeper and more open subsoil through which their fibres may proceed in every direction in search of food. The full benefits of this deepening of the soil, however, can only be expected where the subsoil has previously been laid dry by drains; for it matters not how deep the loosened and permeable soils may be, if the accumulation of water prevent the roots from descending.

2°. Two practical observations, however, may here be added, which the intelligent farmer will always weigh well before he hastily applies this theoretical principle—sound though it undoubtedly be—in a district with which he has no previous acquaintance. It is possible that the deeper soil may contain some substance decidedly noxious to vegetation. In such a case it would be improper at once to mix it with the upper soil. Good drains must be established, they must be allowed some time to act, and the subsoil plough will be used with advantage, before any portion of such an under-soil can be safely brought to the surface. The subsoil plough and the drain, indeed, as I have already mentioned, are the most certain available remedies for such a state of the subsoil. In many localities, however, the exposure of such an under-soil to a winter's frost, or to a summer fallow, will so far improve and mellow it, as to render it capable of being safely mixed with the surface soil. Unless, however, this *mellowing* be effected at once, and before admixture, a long time may elapse ere the entire soil attain to its most perfect condition.*

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* The Marquis of Tweedale, in his home-farm at Yesters, has raised his land in value eight times (from 5s. to 40s. per. acre), by draining and deep ploughing. After draining the fields of stiff clay, with streaks of sand in the subsoil, are turned over to a depth of 12 or 14 inches, by two ploughs

Again, it is known that some districts, for reasons perhaps not well understood, are more infested than others with insects that attack the corn or other crops. These insects, their eggs, or their larvæ, generally bury themselves in the undisturbed soil, immediately beyond the ordinary reach of the plough. If they remain wholly undisturbed during the preparation of the soil, some species remain in a dormant state, and the subsequent crop may in a great measure escape. Plough the land deeper than usual, and you bring them all to the surface. Do this in the autumn, and leave your land unsown, and the frost of a severe winter may kill the greater part, so that your crops may thereafter grow in safety. But cover them up again along with your winter corn, or let this deep ploughing be done in the spring, and you bring all these insects within reach of the early sun, and thus call them to life in such numbers as almost to insure the destruction of your coming crop. It is to something of this kind that I am inclined to attribute the immediate failures which have attended the trial of deep ploughing in certain parts of England. Thus in Berkshire, certain soils which are usually ploughed to a depth of only *two* inches, yielded almost nothing when deeper ploughing was more lately tried upon them—the crop was almost entirely destroyed by insects. So also in the north of Yorkshire, where deep ploughing has recently been attempted, the wheat crop on land so treated was observed to suffer more from the worm than on any other spot. Such facts as these, therefore, show the necessity of caution on the part of the practical man, and especially of the land agent or steward, however correct may be the principles on which his general practice is founded. Failures such as the above do not show

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(two horses each) following one another, the under 6 inches being thrown on the top. In this state it is left to the winter's frost, when it falls to a yellow marly looking soil. It is now ploughed again to a depth of 9 or 10 inches, by which half the original soil is brought again to the surface. By a cross ploughing this is mixed with the new soil, after which the field is prepared in the usual way for turnips. But it is observed that if the ploughing has been so late that the subsoil has not had a proper exposure to the winter's cold, the land on such spots does not for many years equal that which was earlier ploughed. The reason is, that when once mixed up with the other soil the air has no longer the same easy access into its pores.

the principle on which deep ploughing is recommended to be false, or the practice to be in any case reprehended; but it does show that a knowledge of natural local peculiarities, and some study of ancient local practice, may, in an important degree, influence our mode of procedure in introducing more improved methods of husbandry into any old agricultural district.

§ 6. *Improvement of the soil by mixing.*

There are some soils so obviously defective in constitution, that the most common observer can at once pronounce them likely to be improved by mechanical admixtures of various kinds. Thus peaty soils abound too much in vegetable matter; a mixture of earthy substances, therefore, of almost any common kind is readily indicated as a means of improvement. In like manner we naturally impart consistence to a sandy soil by an admixture of clay, and openness and porosity to stiff clays by the addition of sand.

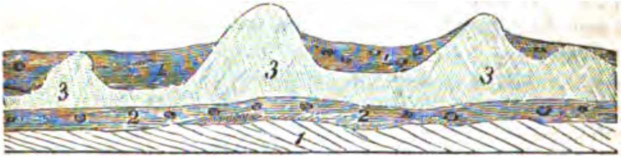
The first and obvious effect of such additions is to alter the physical qualities of the soil—to consolidate the peats and sands, and to loosen the clays. But we have already seen that the fertility of a soil, or its power of producing a profitable return of this or that crop, depends in the first place on its chemical constitution. It must contain in sufficient abundance all the inorganic substances which that crop requires for its daily food. Where this is already the case, as in a rich stiff clay, a decided improvement may be produced by an admixture with siliceous sand, which merely separates the particals mechanically, and renders the whole more porous. But let the clay be deficient in some necessary constituent of a fertile soil, and such an 'addition of siliceous sand would not produce by any means an equal benefit. It may be proper to add this sand with the view of producing the mere physical alteration, but we must add some other substance also for the purpose of producing the necessary chemical change.

The good effects which almost invariably follow from the addition of clay to peaty or sandy soils are due to the production at one and the same time of a physical and of a chemical change. They are not only rendered firmer or more solid by the admixture of clay, but they derive from this clay at the same time some of those mineral substances which they previously contained in less abundance.

The addition of marl to the land acts often in a similar two-fold capacity. It renders clay lands more open and friable, and to all soils brings an addition of carbonate, and generally of phosphate of lime, both of which are proved by experience to be not only very influential, but to be absolutely necessary to healthy vegetation.

That much benefit to the land would in many instances accrue from such simple admixtures as those above adverted to, where the means are available, will be readily granted. The only question on the subject that ought to arise in the mind of a prudent man, is that which is connected with the economy of the case. Is this the most profitable way in which I can spend my money? Can I employ the spare labour of my men and horses in any other way which will yield me a larger return? It is obvious that the answer to these questions will be modified by the circumstances of the district in which he lives. It may be more profitable to drain,—or labour may be in great request and at a high premium,—or a larger return may be obtained by the investment of money in purchasing new than in improving old lands. It is quite true that the country at large is no gainer by the mere transfer of land from the hands of A to those of B, and that he is undoubtedly the most meritorious citizen who, by expending his money in improving the soil, virtually adds to the breadth of the land, in causing it to yield a larger produce. Yet it is no less true that the employment of individual capital in such improvement is not to be expected *generally* to take place, unless it be made to appear that such an investment is likely to be as profitable as any other within the reach of its possessor. It seems to be established beyond a doubt, that in very many districts no money is more profitably invested, or yields a quicker return, than that which is expended in draining and subsoiling—and yet in reality one main obstacle to a more rapid increase in the general produce of the British soil is the practical difficulty which exists in convincing the owners and occupiers of the soil that such is the case, or would be the case, in regard to their own holdings. The more widely a knowledge of the entire subject, in all its bearings, becomes diffused, the less it is to be hoped will this difficulty become—for the economist, who regards the question of improvement as a mere matter of profit and loss, cannot strike a fair balance unless he knows the several items he may prudently introduce into each side of his account.

Thus in reference to the special point now before us, it seems reasonable to believe that, in a country such as that here represented, where alternate hills of sand (3), and hollows, and flats of clay (4) occur, there may be many spots where both kinds of soil—being near each other—might be improved by mutual admixture, at a cost of labour which the alteration in the quality of the land might be well expected to repay. In this condition is a considerable portion of the Eastern half of the county of Durham, and, especially, I may mention the neighbourhood of Castle Eden, where a cold, stiff, at present often poor clay rests upon red, rich-looking, loamy sand, in many places easily accessible, and by admixture with which its agricultural capabilities may be expected to improve. In this locality, and in many others besides, those having a pecuniary interest in the land rest satisfied that their fields are incapable of such improvement, or would give no adequate return for the outlay required, without troubling themselves to collect and compare all the facts from which a true solution of the question can alone be drawn.



Besides such general admixtures for the improvement of land, the geological formation of certain districts places within the reach of its intelligent farmers means of improvement of a special kind, of which they may often profitably avail themselves. Thus both in Europe and America the *green-sand* soils (p. 358) are found to be very fertile, and the sandy portions of this formation are often within easy distance of the stiff clays of the gault, and of the poor soils of the chalk, with either of which they might be mixed with most beneficial effects. The soils that rest on the *new*, and even on some parts of the *old red sandstone*, are in like manner often within an available distance of beds of red marl of a very fertilizing character (p. 363), while in the granitic and trap districts the materials of which these rocks consist, if mixed with judgment, may be made materially to benefit some of the neighbouring soils. To this point, however, I shall draw your attention again in my next lecture when treating of mineral manures.

LECTURE XV.

Improvement of the soil by chemical means. Principles on which all manuring depends. Mineral, vegetable, and animal manures. Saline manures. Carbonates.—Pearl-ash. Sulphates.—Glauber salts. Chlorides.—Common salt. Nitrates.—Nitrate of soda. Phosphates.—Phosphate of lime. Silicates.—Silicate of potash. Saline mixtures.—Vegetable ashes. Prepared granite. Use of lime.

The mechanical methods of improving the soil, described in the preceding section, are few in number and simple in theory. They are so important, however, to the general fertility of the land, that were they judiciously employed over the entire surface of our islands, they would alone greatly increase the average produce of the British and Irish soils. I may, indeed, repeat what was stated in reference to draining (p. 10), that the full effect of every other means of improving the soil will be obtained in those districts only where these mechanical methods have already been had recourse to.

The chemical methods of improving the soil are founded upon the following principles, already discussed and established :—

1°. That plants obtain from a fertile soil a variable proportion of their organic food ;—of their nitrogen probably the greatest part.

2°. That they require inorganic food also of various kinds, and that this they procure solely from the soil.

3°. That different species of plants require a special supply of different kinds of inorganic food, or of the same kinds, in different proportions.

4°. That of these inorganic substances one soil may abound or be deficient in one, and another soil in another; and that, therefore, this or that plant will prefer to grow on the one or the other accordingly.

On these few principles the whole art of improving the soil by chemical means—in other words of beneficially manuring the soil—is founded.

It must at the same time be borne in mind, that there are three distinct methods of operation by which a soil may be improved :—

1°. By *removing* from it some noxious ingredient. The only method by which this can be effected is by draining,—providing an outlet by which it may escape, or by which the rains of heaven, or water applied in artificial irrigation, may wash it away.

2°. By *changing* the nature or state of combination of some noxious ingredient, which we cannot soon remove in this way; or of some inert ingredient which, in its existing condition, is unfit to become food for plants. These are purely chemical processes, and we put them respectively in practice when we add lime to peaty soils, or to such as abound in sulphate of iron (p. 313), when by admitting the air into the subsoil we change the prot-oxide into the per-oxide of iron (p. 311), or when by adding certain known chemical compounds we produce similar beneficial chemical alterations upon other compounds already existing in the soil.

3°. By *adding* to the soil those substances which are fitted to become the food of plants. This is what we do in strictly *manuring* the soil—though we are as yet unable in many cases to say whether that which we add promotes vegetation by actually feeding the plant and entering into its substance—or only by preparing food for it. There is reason to believe, however, that many substances, such as potash, soda, &c., act in several capacities,—now preparing food for the plant in the soil, now bearing it into the living circulation, and now actually entering into the perfect substance of the growing vegetable. In order to steer clear of the difficulty which this circumstance throws in the way of an exact classification of the chemical substances applied to the soil, I shall consider generally under the name of *manures, all those substances which are usually applied to the land for the purpose of promoting vegetable growth* ;—whether those substances be supposed to do so directly by feeding the plants, or only indirectly, by preparing their food, or by conveying it into their circulation.

Manures, then, in this sense are either simple, like common salt and nitrate of soda, or they are mixed, like farmyard manure and the numerous artificial manures now on sale. Or, again, they consist of substances of mineral, of vegetable, or of animal origin. The latter is the more natural, and is by far the most useful, classification. We shall, therefore, consider the various substances employed in improving the soil—or what is in substance the same thing in promoting vegetation,—in the following order:—

1°. *Mineral manures*—including those substances, whether simple or mixed, which are of mineral origin, or which consist entirely of inorganic or mineral matter. Under this head the use of lime and of the ashes of plants will fall to be considered.

2°. *Vegetable manures.*—These are all of natural origin, and are all mixtures of organic and inorganic matter.

3°. *Animal manures*, which are also mixtures, but, owing to their immediate origin, differ remarkably in constitution from vegetable substances.

§ 1. *Of mineral manures.*

Mineral manures may be conveniently considered under the two heads of saline and earthy manures.

A.—SALINE MANURES.

1°. *Carbonate of potash.*—This substance, in the form either of crude potash or of the pearl-ash of the shops, has hitherto been considered too high in price to admit of its extensive application in the culture of the land.

2°. *Carbonate of soda.*—This remark, however, does not apply to the carbonate of soda (common soda of the shops), which is sufficiently low in price (£11 a ton) to allow of its being applied with advantage under many circumstances. In the case of grass lands, which are overrun with moss—of such as abound largely in vegetable matter or in noxious sulphate of iron—a weak solution applied with a water cart might be expected to produce good results. It might be applied in the same way to fields of sprouting corn, or in fine powder as a top-dressing in moist weather—

and generally wherever wood ashes are found useful to vegetation.

Many experiments have shown that both of these substances may be employed in the field with advantage to the growing crop—but further trials are necessary to show how far the practical farmer may safely use them with the hope of profit. In gardening they greatly hasten the growth and increase the produce of the strawberry,* and in garden culture, generally, where the cost of the manure employed is of less consequence, more extended trials would, no doubt, lead to useful results.

The quantity of these substances which ought to be applied to our fields, in order to produce the beneficial effect which theory and practice both lead us to expect, will depend much upon the nature of the soil in each locality and on the kind of manuring to which it has previously been subjected. By referring to our previous calculations (p. 327), it will be seen that upwards of 800 lbs. of these carbonates† would be necessary to replace all that is extracted from the soil by the entire crops during a four years' rotation. But in *good* husbandry every thing is returned to the soil in the form of manure which is not actually sent to market and sold for money. That is—the grain only of the corn crops, the dairy produce, and the live stock are carried off the land.‡ Less than 40 lbs. per acre of the mixed carbonates would replace all that is contained in the grain, and if we suppose as much to be present in the other produce sold, we have 80 lbs. for the quantity necessary to be restored to the land by the good husbandman every four years, in order to keep his farm permanently in the same condition. There are, however, in most soils certain natural sources of supply (pp. 306, 305) by which new portions of these alcalies are continually conveyed to them. Hence it is seldom necessary to add to the land as much of these substances as we carry off; and therefore from 40 to 60 lbs. per acre, of either of them, may be considered as about the largest quantity which, in a well-managed farm, need be added in order to give a fair trial to their agricultural value. Half a cwt. of the potash will cost less than 15s., and of the soda less than 6s., or of a mixture, in equal quantities, less than 21s. at their present prices.

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* Mr. Fleming, of Barochan, has informed me that he found this to be the case with the common potash; and Mr. Campbell, of Islay, with the common soda of the shops. They should be applied early in the spring, and in the state of a very weak solution. Wood-ashes would probably produce a similar effect.

† 390 lbs. of dry pearl ash and 440 lbs. of crystallised carbonate of soda.

‡ In *bad* husbandry much more is carried off the land by the waste of liquid and other manure.—See the succeeding chapter "*On animal manures.*"

Theory of the action of potash and soda.

But upon what theoretical grounds is the beneficial action of potash and soda upon vegetation explained? This question, to which I have already more than once drawn your attention (pp. 119 and 274), it will be proper here briefly to consider.

a. The first and most obvious purpose, served by the presence of these alcalies in the soil, is that of yielding readily to the growing plant such a full supply of each as may be essential to its healthy growth. If the roots can collect them from the soil slowly only, and with difficulty, the growth of the plant will necessarily be retarded; while in situations where they naturally abound, or are artificially supplied, the crops will as certainly prove both more early and more abundant—provided no other essential food be deficient in the soil.

In reference to this mode of action it will occur to you that potash is the more likely of the two to be beneficial to our cultivated crops, inasmuch as the ash of those plants which are raised for food is generally much more rich in potash than in soda.* But this may possibly arise from the more abundant presence of potash in the soil generally, since some chemists are of opinion that soda may take the place of potash in the interior of plants, *without materially affecting their growth.*† This hypothesis, whatever may be its theoretical value, will prove useful to practical agriculture if it lead to experiments from which the relative action of each of these carbonates, in the same circumstances, may be deduced,—and the *specific* influence of each, in promoting the growth of particular plants, in some degree determined. Potash (or wood-ashes) aids the growth of corn after turnips or potatoes (Lampadius)—would soda do the same? Carbonate of soda assists in a remarkable manner the growth of buck-wheat (Sprengel)—would the same good effects follow from the use of potash?

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* See the tabular details given in Lecture X., § 3.

† Berzelius *Chimie*, VI., p. 733, (Edit. 1832).

b. Another purpose which these carbonates are supposed to serve, is that of combining with, and rendering soluble, the vegetable matter of the soil, so as to bring it into a state in which it may be readily conveyed into the roots of plants. They may in this case be said to *prepare* the food of plants. That they are really capable of forming readily soluble compounds with the humic acid, and with certain other organic substances which exist in the soil, is certain. Those, however, who maintain with Liebig that plants imbibe *all* their carbon in the form of carbonic acid, will not be willing to admit that this property of the above carbonates can either render them useful to vegetation, or account for the beneficial action they have so often been observed to exercise. From this opinion we have already seen reason (pp. 87 to 89) to dissent, and we are prepared, therefore, to concede that potash and soda, in the form of carbonates, *may* act beneficially upon vegetation—by preparing the organic matter of the soil for entering into the roots of plants, and thus administering to their growth.

This preparation also may be effected either by their directly combining with the organic matter, as they are known to do with the humic and other acids which exist in the soil; or by their disposing this organic matter, at the expense of the air and of moisture, to form new chemical compounds which shall be capable of entering into the vegetable circulation. This *disposing* influence of the alcalies, and even of lime, is familiar to chemists under many other circumstances.

This mode of action of the carbonates of potash and soda can be exercised in its fullest extent only where vegetable matter abounds in the soil. It is stated by Sprengel[*] accordingly as the result of experiment, that they are most useful where vegetable matter is plentiful, and that they ought to be employed more sparingly, and with some degree of hesitation, where such organic matter is deficient.

c. We have already seen, during our study of the composition of the ash of plants (pp. 318 to 335), how very important a substance silica is, especially to the grasses and to the stems of our various corn-bearing plants. This silica exists very frequently in the soil in a state in which it is insoluble in pure water, and yet is more or less readily taken up by water containing carbonate of potash or carbonate of soda. And as there is every reason to believe that nearly all the silica they contain is actually conveyed into the circulation of plants by the agency of potash and soda,[†] it is not unlikely that a portion of the beneficial action of these substances, especially upon the grass and corn crops, may be due to the quantity of silica they are the means of conveying into the interior of the growing plants.

d. Another mode in which these substances act, more obscurely, perhaps, though not less certainly, is by disposing the organic matters contained in the sap of the plant to form such new combinations as may be required for the production of the several parts of the living vegetable. I have on a former occasion illustrated[‡] to you the very remarkable changes which starch may be made to undergo, without any essential alteration in its chemical composition—how gum and sugar may be successively produced from it, without either loss or gain in respect of its original elementary constitution. We have seen also how the presence of a comparatively minute quantity of diastase (p. 175) or of sulphuric acid (p. 167) is capable of inducing such changes, first rendering the starch soluble, and then converting it into gum and into sugar. Analogous, though somewhat different, changes are induced by the psesence in certain solutions of small quantities of potash[§] or soda, as, for example, in milk—the addition of carbonate of soda to which gradually causes (persuades ?) the whole of the sugar it contains to be converted into the acid of milk. Such changes also must be produced or facilitated by the presence of acid and of alcaline substances in the sap of plants; and, though we can as yet only guess at the precise nature of these changes, yet there seems good ground for believing that to facilitate their production is one of the many purposes served by the constant presence of inorganic substances in the sap of plants. Indeed so important is this function considered by some writers upon the nourishment of plants,* that they are inclined to ascribe to it, erroneously however, as I believe, the main influence upon vegetation, of nearly all the inorganic substances which are found in the ash of plants, and therefore are known to enter into their circulation.

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[*] *Lehre vom Dünger*, p. 402.

[†] In the state of *silicates*.—See pp. 119 and 304.

[‡] Lecture VI., § 6, pp. 164 to 168.

[§] It is also shown (p. 165) that, by means of potash, woody fibre may be converted into starch.

e. I only allude to one other way in which these substances may be supposed to have an influence upon vegetation. We have already seen† how important a part the nitric acid produced in the atmosphere or in the soil may be supposed to perform in the general vegetation of the globe. This acid is observed to be more abundantly—either fixed or actually produced in the soils or composts which contain much potash or soda. It may be, therefore, that in adding either of these to our fields we give to the soil the means of bringing within the reach of the roots of our crops a more ready supply of nitric acid, and hence of nitrogen, so necessary a part of their daily food.

3°. *Sulphates of Potash and Soda.*—It is nearly 100 years since Dr. Home, of Edinburgh, observed that these salts produced a beneficial effect upon vegetation. Applied to growing corn they increased the produce by one-fourth. Other experiments, since made in Germany, have shown that they may be applied with manifest advantage both to field crops and to fruit trees (Sprengel), but the price has hitherto been considered too high to admit of their being economically used in ordinary husbandry.

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* See especially Hlubek's *Ernährung der Pflanzen und Statik des Landbaues.*

† Lecture VIII., § 5, 6, 7, pp. 238 to 250.

The manufacture of sulphate of soda in this country, however, has of late years become so much extended, and the price in consequence so much reduced, that I was induced in the spring of last year (1841[*]) again to recommend it to the attention of the practical agriculturists of this country—as likely, either alone or mixed with other substances, to increase in many localities not only the produce but the profit also to be derived from the land.[†] Many experiments were in consequence made in various parts of the country, the details of some of which are given in the Appendix.[‡] When applied at the rate of half a cwt. of the *dry* salt (or one cwt. of crystals) per acre, it produced little effect upon the hay crop, the quantity being probably too small. Applied to hay and rye, at the rate of 84 lbs. of the dry salt, and to potatoes at the rate of 100 lbs., it gave per imperial acre, with

		Undressed.	Dressed with Sulphate.	Increase.
Ray		4480 lbs.	5288 lbs.	808 lbs.
Winter Rye	grain,	640 lbs.	896 lbs.	256 lbs.
	straw,	4096 lbs.	4608 lbs.	512 lbs.
Potatoes		16½ tons.	18¼ tons.	1¾ tons.

The grain of the dressed rye was much heavier than that of the other, and, though nitrate of soda and sal-ammoniac applied to other parts of the same field caused a larger increase in the crop of rye, yet the increase obtained by the use of the sulphate was *cheaper per bushel* than that obtained by the use of either of the other substances.

On beans and peas also the effect produced by it (Appendix, p. 30) was very striking—its action being exerted not upon the straw but upon the pods, increasing their number and enlarging their size.

The results of these experiments, therefore, are such as to encourge further trials. The quantity applied should not be less than one cwt. of the *dry* salt per acre, and it should be put on either in the state of a very weak solution with a water-cart, or sprinkled on the young crop when the ground is moist or when rain is soon expected.

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[*] When the publication of these lectures was commenced.

[†] See Appendix, page 1, also published in the form of a separate tract—"*Suggestions for Experiments in Practical Agriculture*," *No. I.*

[‡] Pages 16 to 30. See also "*Suggestions for Experiments in Practical Agriculture*," *No. II.*

4°. *Sulphate of Magnesia* (*Epsom Salts*) was found by Dr. Home to promote vegetation almost in an equal degree with the sulphates of potash and soda, but the usually high price of this compound, among other causes, has hitherto prevented it from being tried upon an extensive scale. The manufacture of this article also has of late years, however, been so much extended and simplified, that the refined salts for medicinal purposes may be purchased as low as 8s. a cwt.,* and the impure salts of the Yorkshire and other alum works at a much lower rate. So much capital indeed has now been embarked in the manufacture of the sulphates and carbonates of soda and magnesia (p. 282), and it is so desirable on many accounts to discover new outlets for the products of these important manufactories, that were there only theoretical reasons for believing them likely to benefit practical agriculture, it would be desirable to make trial of their effects upon the land. But their favourable influence has already been shown, and it remains, therefore, only to work out the details by which their application to this or that soil or crop shall be so regulated as to yield a fair and constant profit to the farmer who employs them.

I have elsewhere (Appendix p. 5) recommended the application of sulphate of soda at the rate of 1 cwt. of the *dry* salt or of 2 cwt. of crystals (cost 10s. or 11s.) per acre. The Epsom salts are only sold in crystals, and 1½ cwt. (cost 12s.) in this form should be nearly equal in efficacy upon the land to 2 cwt. of crystallized sulphate of soda. In this proportion, therefore, it would be proper to apply it to the young crops, especially of wheat, clover, peas, beans, and other leguminous plants.

5°. *Sulphate of Lime* (*Gypsum*) has been long and extensively applied to the land in various countries and to various crops. In Germany its influence has been most generally beneficial upon grass and red clover, while in many parts of the United States it is applied with advantage to almost every crop. In the former country and in England, it is usually dusted over the young plants in early spring; in America it is frequently sown with the seed, or, in the case of potatoes, put into the drills or holes along with the manure. The propriety of adopting the one rather than the other of these methods will depend upon the nature of the soil and upon the climate. Gypsum requires much water to dissolve it, and in dry soils, climates, or seasons, it might readily fail to influence the crop at all, if applied in the form of a top dressing only.

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* From the Messrs. Cookson's, of the Jarrow Alkali Works, near Newcastle.

It would appear that the time and mode of its application has more influence upon its activity than we might suppose—since, according to Professor Körte, when applied to clover at different periods in the spring the produce of different parts of the same field was in the following proportions:—

Undressed	100 lbs.
Top dressed on the 30th of March ...	132 lbs.
.... 13th of April ...	140 lbs.
.... 27th of April ...	156 lbs.*

The effect of a top dressing of gypsum seems therefore to be greatest when it is applied after the leaves have been pretty well developed.†

Theory of the action of these sulphates.

a. It does not seem difficult now to account for the *general* action of these several sulphates of potash, soda, magnesia, and lime. The explanation may be deduced partly from recent chemical analyses, and partly from agricultural experiments more lately made by practical men.

It has been found, for example, that sulphur is a constant and apparently necessary constituent of the gluten according to the ordinary practice of husbandry, the sulphate of soda has the best chance of proving useful to vegetation, not only because it is more soluble, and is, therefore, more independent of the seasons, but because it is capable of supplying two different substances—sulphuric acid and soda—neither of which are directly added in the ordinary manuring of the land, but both of which the plants may find difficulty in obtaining.

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* *Möglinsche Jahrbucher*, I., p. 85, quoted in Hlubek's *Pflanzennährung*.

† Can the result here mentioned have any connection with the fact observed by Peschier, that gypsum laid upon the leaves of plants is gradually converted into carbonate, its sulphuric acid being absorbed?

d. Another consideration will indicate further *special* applications of these several sulphates, independant of the sulphuric acid which they in common contain. If we refer to the table (p. 323) in which is exhibited the constitution of the ash of the several clovers and grasses, we find the constituents of our sulphates to be present in 100 parts of the ash in the following proportions:—

	Rye Grass Hay.	Red Clover.	White Clover.	Lucerne.	Sainfoin.
Potash - -	8·81	19·95	31·05	13·40	20·57
Soda - -	3·94	5·29	5·79	6·15	4·37
Lime - -	7·34	27·80	23·48	48·31	21·95
Magnesia -	0·90	3·33	3·05	3·48	2·88
Sulphuric Acid	3·53	4·47	3·53	4·04	3·41

Of the two clovers the red contains more lime and much less potash, therefore the sulphate of lime is more likely to benefit the red clover, and the sulphate of potash the white, which is consistent with the results of experiment. A similar difference exists between lucerne and sainfoin, to the former of which lime and soda are more necessary than the latter. The first column under rye grass shows, on the other hand, how very much smaller a proportion of all the four—potash, soda, lime, and magnesia—is required by this green crop than by the others; and therefore that the same weight of any one of these sulphates, which, when applied as a top dressing to one crop (rye grass) would cause it to thrive luxuriantly, may be insufficient to supply the most necessary wants of another crop (clover or sainfoin). Not only the *kind* of mineral manure, therefore, which we mix with the soil, but the *quan-*

tity also must be determined by the kind of crop we intend to raise.*

6°. *Nitrates of Potash and Soda.*—The efficacy of these two substances as manures in certain circumstances is now generally acknowledged, though the disappointments which have occasionally attended their use, naturally cause the practical farmer to hesitate still, before he applies them in any quantity to his land. As these salts, especially the nitrate of soda, are comparatively abundant in nature,—as they are really beneficial in many cases, and can be employed with a profit,—as their use in practical agriculture has recently excited considerable interest,—and as many experiments have in consequence been made with them upon various crops,—I shall briefly direct your attention to the most important facts which have yet been established in regard to their action upon the growing plant.

a. Apparent effects of the Nitrates.—The first visible effect of the nitrates upon every crop is to impart a dark green colour to the leaves and stems. 2°. They then hasten, increase, and not unfrequently prolong the growth of the plant. 3°. They *generally* cause an increase both in the weight of hay or straw, and of corn—though the colour and growth are occasionally affected without any sensible increase of the crop. 4°. The hay or grass produced is always more greedily eaten by the cattle than that which has not been dressed, even when the quantity is not affected;—but the grain is usually of inferior quality, bringing a somewhat less price in the market, and yielding a smaller produce of flour.

Its principal action seems to be expended in promoting the growth—that is, increasing the production of woody fibre, either in the stem or the ear, without so much affecting, except indirectly, the quantity of seed.

Illustrations.—1°. Mr. Pusey observed that the increase of his wheat crop, on the Oxford clay, where nitrate of soda was applied, arose from there being *no underling straws with short ears* as in the undressed, but all were of equal length and consequent fullness and ripeness.† The nitrate had merely promoted the growth.

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* For the theoretical opinions of other authors, in regard to the action of *gypsum*, see the Appendix, No. VI.

† *Royal Agricultural Journal*, II., p. 120.

according to the ordinary practice of husbandry, the sulphate of soda has the best chance of proving useful to vegetation, not only because it is more soluble, and is, therefore, more independent of the seasons, but because it is capable of supplying two different substances—sulphuric acid and soda—neither of which are directly added in the ordinary manuring of the land, but both of which the plants may find difficulty in obtaining.

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Lime - -	7·34	27·80	23·48	48 31	21·95
Magnesia -	0·90	3·33	3·05	3·48	2·88
Sulphuric Acid	3·53	4·47	3·53	4·04	3·41

Of the two clovers the red contains more lime and much less potash, therefore the sulphate of lime is more likely to benefit the red clover, and the sulphate of potash the white, which is consistent with the results of experiment. A similar difference exists between lucerne and sainfoin, to the former of which lime and soda are more necessary than the latter. The first column under rye grass shows, on the other hand, how very much smaller a proportion of all the four—potash, soda, lime, and magnesia—is required by this green crop than by the others; and therefore that the same weight of any one of these sulphates, which, when applied as a top dressing to one crop (rye grass) would cause it to thrive luxuriantly, may be insufficient to supply the most necessary wants of another crop (clover or sainfoin). Not only the *kind* of mineral manure, therefore, which we mix with the soil, but the *quan-*

tity also must be determined by the kind of crop we intend to raise.*

6°. *Nitrates of Potash and Soda.*—The efficacy of these two substances as manures in certain circumstances is now generally acknowledged, though the disappointments which have occasionally attended their use, naturally cause the practical farmer to hesitate still, before he applies them in any quantity to his land. As these salts, especially the nitrate of soda, are comparatively abundant in nature,—as they are really beneficial in many cases, and can be employed with a profit,—as their use in practical agriculture has recently excited considerable interest,—and as many experiments have in consequence been made with them upon various crops,—I shall briefly direct your attention to the most important facts which have yet been established in regard to their action upon the growing plant.

a. Apparent effects of the Nitrates.—The first visible effect of the nitrates upon every crop is to impart a dark green colour to the leaves and stems. 2°. They then hasten, increase, and not unfrequently prolong the growth of the plant. 3°. They *generally* cause an increase both in the weight of hay or straw, and of corn—though the colour and growth are occasionally affected without any sensible increase of the crop. 4°. The hay or grass produced is always more greedily eaten by the cattle than that which has not been dressed, even when the quantity is not affected;—but the grain is usually of inferior quality, bringing a somewhat less price in the market, and yielding a smaller produce of flour.

Its principal action seems to be expended in promoting the growth—that is, increasing the production of woody fibre, either in the stem or the ear, without so much affecting, except indirectly, the quantity of seed.

Illustrations.—1°. Mr. Pusey observed that the increase of his wheat crop, on the Oxford clay, where nitrate of soda was applied, arose from there being *no underling straws with short ears* as in the undressed, but all were of equal length and consequent fullness and ripeness.† The nitrate had merely promoted the growth.

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* For the theoretical opinions of other authors, in regard to the action of *gypsum*, see the Appendix, No. VI.

† *Royal Agricultural Journal*, II., p. 120.

2°. "It affected the tops of the *potatoes*, but the produce of bulbs was less both by weight and measure" (Mr. Grey, of Dilston). "On peas, in a thin sandy soil, subsoil gravel, it had much effect on the colour and strength of the stems, and on the state of forwardness, but when ripe, though the straw was stronger, there was no difference in the crop of peas" (Colonel Campbell, of Rozelle). "On land in high condition it did harm by forcing the straw at the expense of the ear" (Mr. Barclay). "It appeared to act strongly, and there was a greater bulk of straw, but the increase of grain was only 50 lbs. per acre" (Sir Robert Throckmorton). In another experiment of Mr. Barclay's the straw was very strong, and much of the wheat laid, but the undressed sold for 4s. a bushel more, and there was no profit.

In all these cases the nitrate promoted chiefly the growth of the stem, or the production of woody fibre. The inferior quality of the grain and yield of flour was owing to this action. The grain was enveloped in a thicker covering of the woody matter which forms the skin or bran.

3°. "The turnips after the nitrated wheat are decidedly better, *the tops are still growing* and luxuriant, while on the other part they are beginning to fall" (Hon. H. Wilson). They seem, therefore, in some cases, at least to prolong the growth.

From the above statements we seem to derive an explanation why the effects of the nitrate should have been so universally observed upon the grasses and clovers—while in regard to its application to *corn crops* they indicate this important—

PRACTICAL RULE.—Not to apply the nitrates upon land or under circumstances where there is already a sufficient tendency to produce straw.

b. Effects of the nitrates upon the QUANTITY *of the crop.*—Cases have occurred where the nitrates have failed to produce any apparent effect at all—others where the colour was affected and the growth promoted without any ultimate increase of crop—and others again where the application of these salts was decidedly injurious. These failures are deserving of a close consideration, but let us first attend to the amount of benefit derived from their use where it has been attended with success.

I.—EFFECT ON COMMON AND CLOVER HAY.

Locality.	PRODUCE PER ACRE.				Quantity of Nitrate of Soda applied per acre, and nature of soil.
	Undressed.		Dressed.		
	tons.	cwt.	tons.	cwt.	
Aske Hall, *Earl of Zetland.*	2	12	3	4	1 cwt., on a thin light soil, subsoil clay upon lime-stone.
At Erskine, *Lord Blantyre.*	2	0½	3	0½	120 lbs., good light soil, subsoil gravel.
	2	1	2	10	Ditto, clay soil on clay subsoil.
Barochan, *Mr. Fleming.*	1	6	2	4½	160 lbs., stiff clay, after wheat.
	2	11	2	19½	Ditto, light clay loam, drained after barley.
Dilston, *Mr. Grey.*	2	10	3	18	1 cwt., meadow hay, soil not mentioned.
Farnham, Suffolk, *Mr. Muskett.*	2	4½	3	1½	150 lbs., clover hay, soil not mentioned.
Methven Castle, *Mr. Bishop.*	1	1½	2	3	1 cwt. nitrate of potash and 1½ of nitrate of soda, had each the same effect on a heavy damp loam, partially drained.

On the other hand, Mr. Barclay says that, on his heavy clay lands (plastic clay), in Surrey, near the edge of the chalk, it is almost always a failure; and the Messrs. Drewitt, of Guildford, that on their chalk soils, the additional produce of hay, whether on upland or meadow, does not repay the expense.

II.—ON BARLEY.

Locality.	PRODUCE.				Quantity per acre, and kind of soil.
	Undressed.		Dressed.		
	grain.	straw.	grain.	straw.	
	bush.	cwt.	bush.	cwt.	
Surrey, *Mr. Barclay.*	44¾	16¼	55½	20¼	1 cwt. on light soil with chalk subsoil.
Newton Hall, Northumberland, *Mr. Jobling.*	47	26	59	36	1 cwt. on strong turnip land.
Suffolk, *Hon. H. Wilson.*	18		32		1 cwt. on a poor sandy soil, where the turnips on the preceding year were nearly destroyed by the land blowing.

In Berkshire, on the other hand, it failed (1839), for barley on the light lands, causing them in some cases to be burned up (Mr. Pusey), but the season was droughty.

III.—On Winter Rye.

Mr. Fleming, of Barochan, applied 160 lbs. per acre to rye, upon a strong clay, after potatoes, and obtained—

	Undressed.	Dressed.
Grain	14 bushels.	26 bushels.
Straw	1 ton 7½ cwt. . .	2 tons 19½ cwt.

IV.—Upon Oats.

Locality.	PRODUCE.				Quantity per acre, and kind of soil.
	Undressed.		Dressed.		
	grain.	straw.	grain.	straw.	
	bush.	cwt.	bush.	cwt.	
Bakewell, Derbyshire, *Mr. Greaves*,	48½	25¾	64	38¾	1 cwt. ; heavy soil, clay subsoil.
Court Farm, Hayes, *Mr. Newman*,	46	31	60¾	46½	1 cwt. ; land saturated with water, and out of condition.
Leatherhead, Surrey, *Mr. Barclay*,	40	61	60	90	1 cwt. ; a loam containing flints, on a subsoil of chalk.

Mr. Everett, in Norfolk, obtained an increase of 15 bushels per acre, by the use of ¾ cwt. per acre; and Mr. Calvert, of Ockley Court, of 20 bushels of grain, and 9½ cwt. of straw, by applying 1½ cwt. of nitrate of soda. At Kirkleatham, (North Yorkshire), it had an excellent effect upon oats, on strong land,—and on the strong clays of the Weald of Surrey and Sussex it is said by Mr. Dewdney, of Dorking, to be universally beneficial, particularly when sown on ley ground—paying the grower 27s. to 30s. per acre. "When it has failed, the nitrate has been sown early, and when the land was in a dry state. In these instances the crop was more or less blighted." On the other hand, Mr. Barclay states that, on his strong heavy land, (plastic clay), near the edge of the chalk, in Surrey, it gave no profit.

In most cases, therefore, the nitrate of soda seems capable of producing a large increase in the oat crop—the few failures which are noted must be due either to the state of the weather or to some peculiarities in the physical condition or chemical constitution of the soils on which they were observed.

V.—On Wheat.

Locality.	PRODUCE.				Quantity per acre, and kind of soil.
	Undressed.		Dressed.		
	grain.	straw.	grain.	straw.	
	bush.	cwt.	bush.	cwt.	
Farnham, Suffolk, *Mr Muskett.*	18½		27		1½ cwt.; a poor spongy sandy soil.
Painswick, Gloucester, *Mr. Hyett.*	33½		43½		1 cwt.; a *stone-brash* soil abounding in carbonate of lime.
Fairford Park, Gloucester, *Mr. Raymond Barker*	26	15	33¼	21¾	1 cwt.; on a lightstone-brash poor thin soil.
Mr. Dugdale.	42	34	54	38½	1 cwt. nitrate of soda, on a *gravelly* soil; an equal weight of *nitrate of potash* produced only half bushel of increase(?).
. . . .	32		36½		1 cwt. nitrate of soda on a strong clay. Both portions were previously limed.
Court Farm, Hayes, *Mr. Newman.*	14¾	18½	20	25¾	1 cwt.; on a very thin crop, injured by an unfavourable autumn. Soil not stated.
Brandon, Suffolk, *Hon. Mr. Wilson.*	27½		32		1 cwt. on a fair light soil.
	30½		36		Do., loamy, better land.
Surrey, *Mr. Barclay,*	33¾	20	39¾	23	1 cwt.; soil loamy, resting on chalk, straw strong, and much wheat laid.*
	31	24½	33½	27¾	
Faringdon, *Mr. Pusey,*	27	24¾	39½	34¾	Do. on heavy soil, resting on the Oxford clay. *But all these very different results were obtained in the same field.*
	21¾	20¼	26	25½	
	20½	20¼	24⅙	24½	
Ockley Court, *Mr. Calvert.*	33	25¾	45¾	37¾	Do. corn generally laid, soil not mentioned.
Newton Hall, *Mr. Jobling.*	30	29¼	36	35½	1 cwt. soil not mentioned.
Cirencester, *Dr. Daubeny.*	27½	16	31¾	20½	1 cwt. nitrate of potash.
			27⅙	15½	Do. nitrate of soda, soil and subsoil clay, resting on the corn-brash.
Rozelle, near Ayr, *Col. Campbell.*	35	31½	47	52	180 lbs. nitrate of soda.
			42	76	Do. nitrate of potash. Soil not mentioned.†

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* The dressed grain sold at 4s. less than the undressed, and there was no profit; the nitrate failed on heavy land, and on land in high condition.

† The produce of straw, especially from the saltpetre, is very surprising. It is stated at 518 and 764 stones for the two lots respectively. I suppose the acres to be Scotch, and the stones 14 lbs.

VI.—On Turnips.

At Rozelle the Swedes were improved several tons an acre by the use of the nitrate of soda (Mr. Campbell). At Dorking it was very beneficial as a top-dressing to the Swedes and white turnips, when sown broad-cast at the rate of 1¼ cwt. per acre (Mr. Dewdney.) In neither of these cases is the soil described. On thin stony land upon chalk at Elmshurst, Bucks, turnips manured with nitrate alone, were very superior to those to which 10 loads an acre of farm-yard manure had been applied (Mr. Burgess). The only numerical results with which I am acquainted are those of Mr. Barclay on a loamy soil resting on chalk. His crop of turnips was

30½ cwt. when dressed with bones and wood ashes, each 15 bushels.
31 cwt. when dressed with 1 cwt. of nitrate of soda, drilled in.
35 cwt. when seed and nitrate were both broad-cast.
38 cwt. when the seed was drilled and the nitrate broad-cast.

On the other hand, Lord Zetland thought it did no good to turnips; Mr. Vansittart that on strong land well dunged it did harm; and the Messrs. Drewitt that on their dry rubbly chalk it had no effect on this crop, though it improved in a remarkable degree the succeeding crop of barley.

We are obviously in want of more numerous and better observations, especially in regard to turnips. The above discordancies will either vanish when we obtain a larger collection of results, or they will find an explanation in the more accurate observations we may expect to obtain in regard to the climate, soil, and geological position of the locality in which each experiment is made. Those practical men who are really desirous of aiding the progress of scientific agriculture,—by which progress not only the national welfare, but their own individual interests also are likely to be promoted,—will do more towards this end by one single experiment in which weights and measures are carefully determined, and the soil, the climate, the geological position and the *lie* of the land, accurately described, than by any number of mere general statements, such as those I have here laid before you in regard to the effect of the nitrates upon the turnip crop.

c. Effect of the nitrates on the QUALITY *of the crop.*—This I have already in some measure alluded to. It so affects the grass and clover as to make it more relished by the cattle. This is usually expressed by saying that the crop is *sweeter*, but since cattle are known to be fond of saline substances, it may be that the grasses are, by these salts, only rendered more savory. It generally also gives a grain (of wheat) of an inferior quality—which has a thicker skin, and yields more bran. This may possibly arise from its having been generally allowed to ripen too long.* A question still undetermined is, whether the flour of nitrated corn is more nutritive than that obtained from corn which has been undressed.

It is generally supposed that those samples of flour which contain the most gluten are also the most nutrative. But hitherto the only experiments which have been made with the view of determining the relative quantities of gluten in samples of grain from the same field, one portion of which had been nitrated, and the other not, are, one made by Dr. Daubeny, and one reported by Mr. Hyett, to the latter of which I have already had occasion, for another purpose, to direct your attention †

In these experiments the flour of the several wheats gave—

	In Dr. Daubeny's Experiment.	In Mr. Hyett's Experiment.
Nitrated	15 per cent. of gluten	23¼ per cent.
Unnitrated	13 per cent. of gluten	19 per cent.
Excess of gluten in the nitrated	2 per cent.	4¼ per cent.

both of which results favour the supposition that one effect of the nitrates upon the quality of the grain is to increase the proportion of gluten, and thus to render them as is generally believed more nutrative. This is a result which theoretically we might be led to anticipate were there no large increase in the quantity of the produce—for then we might naturally expect the nitrogen of the nitric acid to be expended solely in enriching the grain with gluten. But the increase of crop contains in many cases more nitrogen than we add to the soil when we dress it with one cwt. of nitrate of soda per acre, there is, therefore, no excess of nitrogen which we can suppose to go to such an enriching of the more abundant crop of grain. For this reason, among others, I am inclined to doubt whether further careful examination will prove the flour from nitrated grain to be always richer in gluten, and, therefore, more nutritious. At all events increased experiments are to be wished for.

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* See Mr. John Hannam's valuable experiments on the *over*-ripening of corn, in the *Quarterly Journal of Agriculture.*

† See p. 215, note.

d. After-effects of these nitrates.—It is comparatively seldom that any good effects have been observed upon the crop which succeeds that to which the nitrate of soda has been applied. Where they have been noticed it has been chiefly in cases where from some cause (drought or dryness of soil chiefly) the salt has been prevented from exerting its full and legitimate action upon its first application. Thus

1°. Failing to improve turnips on a rubbly chalk soil, it greatly benefitted the succeeding crop of barley (Mr. Drewitt, Guildford, Surrey).

Producing little effect on tares (upon a clay soil?) it improved very much the turnip crop which followed (Mr. Barclay, Leatherhead, Surrey).

2°. In the following instances the benefit was seen on successive crops :—

After producing an increase of one-sixth in the wheat crop both grain and straw, on a light sandy soil (subsoil?) the turnips of the following year were decidedly better where the nitrate had been sown (Hon. H. Wilson, Brandon, Suffolk).

After improving the crop of wheat, the after-crop of hay was also better (Mr. Grey, of Dilston).

At Upleatham, the second cut of clover was nearly as much improved as the first (Mr. Vansittart), and at Dilston the aftermath hay was greater in quantity, and better relished by the cattle (Mr. Grey).

3°. A curious effect is noted by Mr. Rodwell, of Alderton, Woodbridge—*the white clover failed after barley on which nitrate had been used!*

The solubility of these nitrates is so great that in our climate, in seasons of ordinary rain, and on lands *having a moderate degree of inclination*, we should expect that they would be in a great measure washed out of the land in a single year. Hence one reason—even supposing little of the salt to have entered into the roots of the growing crop—why we are not entitled generally to expect any marked effect from it upon a second crop. But let the season be so dry, or the soil so retentive, and the land so level, as to prevent its being all taken up by the roots, or washed away by the rains during one year, and we may then look for after-effects, such as those above described.

e. Circumstances necessary to ensure the success of these saline manures.—This explanation will appear more satisfactory if we glance for a moment at the general conditions which are necessary to *ensure* the success of these or any other saline manures.

1°. They must contain one or more substances which are necessary to the growth of the plant.

2°. The soil must be more or less deficient in these substances.

3°. The weather must prove so moist or the soil be so springy as to admit of their being dissolved, and conveyed to the roots.

4°. They must not be applied in too large a quantity, or allowed to come in contact with the young shoots in too concentrated a form—the water that reaches the roots or young leaves must never be too strongly impregnated with the salt, or if the weather be dry, the plant will be blighted or burned up.

5°. The soil must be sufficiently light to permit the salt easily to penetrate to the roots, and yet not so open as to allow it to be readily washed away by the rains. In reference to this point the nature of the subsoil is of much importance. A retentive subsoil will prevent the total escape of that which readily passes through a sandy or gravelly soil, while an open subsoil again will retain nothing that has once made its way through the surface.

f. Cases in which the nitrates have failed.—A knowledge of the above conditions will enable us in many cases to explain why the nitrates, and other generally useful substances, have failed to exhibit any beneficial effect.

1°. Thus on the light soils of Berkshire the nitrate of soda failed for barley, causing it often to be blighted or burned up. This, no doubt, arose from the drought which may act in one or other of several ways. Either it may prevent the salt from being dissolved at all, and thus hinder its action altogether *for the time*,—or it may retard the solution till the plant has attained such a state of maturity, that it is no longer capable of being equally benefitted by the introduction of the salt into its roots—or after being dissolved, and having partially descended into the soil, the drought may cause it to ascend again with the water which rises to the surface in consequence of the evaporation, and may thus present it to the plant in so concentrated a form as to injure the young shoots—or, finally, the action of the sun upon the green leaf, into which a portion of the salt has already been conveyed by the roots, may be so powerful as to concentrate the saline solution, or to increase its decomposition to such an extent as to cause injury, and consequent blight to the leaf itself.

2°. Again, at Cheadale, in Cheshire (Mr. Austin), the nitrate of soda is said to have had a good effect on wheat and grass where the subsoil was *clay*, but none where the subsoil was gravel, or the soil light and sandy. Here the supply of water in the soil may have been such as to fit it for entering readily into the roots in a proper state of dilution, when the retentive subsoil kept it within reach of the roots,—and yet sufficient, at the same time, to wash it away altogether where the soil and subsoil were too open to be able to retard its passage.

3°. But the occasional occurrence of droughts or the mere physical distinctions of lands as light or heavy, are not sufficient to account for all the recorded differences in the effect of the nitrates. Thus on the clays of the Weald in Sussex (Mr. Dewdney), and on the Oxford clay in Berkshire (Mr. Pusey), the use of the nitrate has been attended with general benefit upon oats and wheat, while on the plastic clay in Surrey (Mr. Barclay), it has been uniformly unsuccessful. The cause of these differences is to be sought for, most probably, in the chemical constitution of the several clays, which are known to be very unlike. The Weald clay is a fresh water formation, contains much fine grained siliceous matter (Part II. p. 356), and is, therefore, comparatively pervious to water. The Oxford clay soils in Berkshire abound in lime, and must, therefore, be in some degree pervious, while the plastic clay of Surrey, where they are stiffest, contain little lime and partake more of the impervious character of pipe clays. It may possibly be in such differences as these that we are to find an explanation of the discordant results of different experimenters, but much further observation is still wanting before we can speak with any degree of confidence upon the subject.

To some an explanation may appear to be most easily given by supposing the one soil to have been rich in soda, while the other was defective in this substance. I shall advert to this point in explaining the *theory* of the action of the nitrates of potash and soda.

g. Circumstances in which the employmiut of the nitrates is most beneficial.—1°. It appears to succeed most invariably in lands which are poor—or out of condition—or on which the corn is thin. Every farmer knows that the most critical time with his crop, as with his cattle, is during the earliest stage of its growth. If it come away quickly and strong during the first few weeks, his hopes are justly high, but if it droop and linger after it is above the ground, his fears are as justly excited. It is in this latter condition of things that an addition of nitrate comes to the aid of the feeble plant, re-animating the pining shoots, and making the thin corn-tiller. On rich lands and thickly growing crops it only causes an over-growth of already abundant straw. According to the experiments of Mr. Barclay, it is most advantageous when sown broadcast.*

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* A valuable precept also is, to proceed cautiously in the use of these expensive substances—making small trials at first, and increasing the quantities employed as success may warrant. By this mode of procedure large losses, of which I have heard, would have been avoided.

2°. Whatever may be the chemical nature of the surface soil, the success of the nitrate seems to be most sure where the land is not wholly destitute of water, where the soil is open enough to allow it readily to descend, and yet the subsoil sufficiently retentive to prevent it from being readily washed away.

3°. I throw it out as a suggestion which has occurred to me from a comparison of the results contained in the above tables, with the kind of soils on which the experiments were made—that probably the presence of lime in the soil may tend to insure the success of the nitrate. In many of the instances of large crops obtained by its aid the land was either naturally rich in lime, or it had, in the ordinary course of husbandry, been previously marled or limed.

h. Theory of the action of the nitrates.—The nitric acid of these salts contains 26 per cent. of its weight of nitrogen—or one cwt. of pure dry nitrate of soda contains about 19 lbs. of nitrogen. This nitrogen we know to be a necessary constituent of plants—one which they obtain almost wholly from the soil—but which nevertheless is generally present in the soil in small quantity only. We have already seen reason (Part I. p. 237) to believe that nitric acid exists naturally in the soil, and is the form in which a large portion of their nitrogen is conveyed into the roots of plants;—when we add it to our fields, therefore, we only aid nature in supplying a compound by which vegetables are usually sustained. And as the young plant will necessarily languish in the absence of one essential kind of food, although every other kind it may require be present in abundance, it is easy to see how the growth of a crop—languidly proceeding upon a soil deficient in nitrogen—may be suddenly re-animated by an application of nitrate of soda to its roots. That this is the true way in which the nitrates generally act is supported by the observation that it is in the poorest soils that they are most useful to the husbandman.

We have already seen also, that one function of the leaf in the presence of the sun is to decompose carbonic acid, and give off its oxygen (Part I. p. 132). It exerts a similar action upon the nitric acid of the nitrates, and upon the sulphuric acid of the sulphates, discharging their oxygen into the air, and thus leaving the nitrogen and sulphur at liberty to unite with the other elementary substances contained in the sap—for the production of the several compounds of which the parts of the growing plant consist.

Nor as we have also seen in a previous lecture* is the good effect of these nitrates upon the crop limited to the supply of that quantity of nitrogen only which they themselves contain. The excess of crop raised by their aid often contains very much more nitrogen than they have been the means of conveying to the roots—even supposing it all to have been absorbed and appropriated by the plant. This arises from the circumstance that the more the plant is made to thrive, the more numerous and extended become its roots also, and these roots are thus enabled to gather from the deeper and more distant soil those supplies of nitrogenous and other necessary food, which would have remained beyond their reach had the plant been allowed to remain in its previously feeble or more languid condition. This has been called the stimulating effect of manures, and some substances have been said to act *only* in this way upon vegetation. This, however, appears to me to be a mistake. The supposed stimulating is always a *secondary* effect, and necessarily follows from the use of *every* kind of manure, which by feeding the plant gives it greater strength, and thus enables it to appropriate other supplies of food which were previously beyond its reach, or which from the absence of one necessary constituent it could not render available to its natural growth.

In this way the *nitrates* act as such—in contra-distinction to the sulphates and other salts of potash and soda. But there is every reason to believe that the potash and soda themselves often aid the effect of the nitric acid with which they are associated. In soils deficient in these alcalies the nitrates would act beneficially, even though nitric acid were already present in abundance,—while, on the other hand, a field that is defective in both constituents of the salt (nitric acid and potash or soda), will be more grateful for the same addition of it than one in which either of them already abounds. In this way, it is not unlikely that the discordant results of experiments, even on the same farm, and especially when the soils are different, may occasionally be explained.

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* See Lecture VIII. pp. 251 and 252.

i. Special *effects of the nitrates of potash and soda.*—On this alcaline constituent of the two nitrates will depend the *special* action of each when applied to the same soil under the same circumstances. It has not yet been clearly made out that any definite special action can be ascribed to them, yet some experiments bearing upon this point have already been published, to which it will be proper to advert. From the study of the special action of given manures upon given crops, practical agriculture has much good to expect.

1°. At Rozelle, near Ayr (1840), nitrate of potash caused oats to come away darker and stronger, and to give a heavy crop, while in the same field nitrate of soda produced no benefit. The soil was inferior, light, and sandy, with a red irony subsoil (Capt. Hamilton). It is added that the crop was injured by the early drought from which it never recovered. This fact renders the special effect of the nitrate of potash in this case doubtful.

2°. In the experiments upon wheat, made by the same gentleman on the same farm,—it is to be presumed upon a similar soil,

	Grain.	Straw.
Nitrate of soda gave . . .	46 bush., and	52 cwt.;
Nitrate of potash gave . .	42 bush., and	76 cwt.;

the produce of straw being here also greatly in favour of the potash salt.

3°. Dr. Daubeny also, in the experiment upon wheat above detailed, found the nitrate of potash to increase the produce considerably while the nitrate of soda caused no increase whatever. The soil was stiff clay upon the cornbrash.

These superior effects of the potash salt may certainly be ascribed to the greater deficiency of the several soils in potash than in soda, a supposition which in the case of the Rozelle experiment is consistent with the fact, that common salt, when tried upon the same land, produced no good effect. If, however, as some suppose (Part III. p. 47), potash and soda are capable of re-placing each other in the living vegetable without materially affecting its growth, this explanation cannot be the true one. Further experiments, however, if carefully conducted, will not fail to clear up this question.

4°. On a gravelly soil Mr. Dugdale obtained an increase of 12 bushels of wheat by the use of nitrate of soda, while nitrate of potash increased the crop by only half a bushel.

This result *may* be explained after the same manner as the preceding—the soil may have already abounded in potash.

5°. In Perthshire, upon a moist loam, Mr. Bishop obtained an equal increase of hay from the use of both nitrates; each having caused the production of a double crop.

The equality in this case may have arisen from the effects being wholly due to the nitric acid, both potash and soda being already abundant in the soil. This is consistent with the situation of the locality in a granite country, and is further supported by the fact, that on the same soil and field ammoniacal liquor, which contains no alcali, produced a still larger increase of produce.

You will understand, however, that all these attempted explanations proceed upon the supposition that the experiments have been both carefully made and faithfully recorded.

7°. *Chloride of Sodium or Common Salt.*—The use of common salt as a manure has been long recommended. In some districts it has been highly esteemed and is still extensively and profitably applied to the land. It has, like many other substances, however, suffered in general estimation from the unqualified terms in which its merits have been occasionally extolled. About a century ago (1748), Brownrigg[*] maintained that the whole kingdom might be enriched by the application of common salt to the soil, and since his time its use has been at intervals recommended in terms of almost equal praise. But these warm recommendations have led sanguine men to make large trials which have occasionally ended in disappointment, and hence the use of salt has repeatedly fallen into undeserved neglect.

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[*] *On the art of making common salt*, p. 153, (London, 1748).

It is certain that common salt has in very many cases been advantageous to the growing crop. Some of the more carefully observed results which have hitherto been published, are contained in the following table:—

Locality.	Produce per Acre.		Quantity applied per acre, and kind of soil
	Unsalted.	Salted.	
UPON WHEAT.	bushels.	bushels.	
Mr. G. Sinclair.	16¾	22¼	11 bushels, after barley.
	11½	21	6½ do., after beans.
	16	17¼	Do. sown with the seed, } after peas.
	—	23¼	Do. dug in with the seed, } after peas.
	12	28¼	5½ bush., applied before sowing, } after turnips.
	—	28¼	11 bush., do. do. } after turnips.
Great Totham, Essex, *Mr. Cuth. Johnson.*	13¾	26¼	5 bush., light gravelly soil.
Barochan, Paisley, *Mr. Fleming.*	25	32	160 lbs., heavy loam, after potatoes.
ON BARLEY. Suffolk. *Mr. Ransom.*	30	51	16 bushels.
ON HAY.	tons. cwt.	tons. cwt.	
At Aske Hall, near Richmond.	2 10	3 12	6 bushels, thin light soil, clay subsoil,
At Erskine, near Renfrew.	2 0	2 12	5 bush., light soil on gravel.
	2 1	2 8	Do., clay soil on clay.

But it is as certain that in many cases when applied to the land, common salt has failed to produce any sensible improvement of the growing crop. And as failures are longer remembered, and more generally made known than successful experiments, the fact of their frequent occurrence has prevented the use of salt in many cases where it might have been the means of much good.

Cause of these failures.—It is not, indeed, to be wondered at, that amid conflicting statements as to its value, the practical farmer should have hesitated to incur the trouble and expense of applying it—so long as no principle was made known to him by which its application to this soil rather than to that, and in this rather than the other locality, was to be regulated.

1°. We know that plants require for their sustenance and growth a certain supply of each of the constituents of common salt, which supply, in general, they must obtain from the soil. If the soil in any field contain naturally a sufficient quantity of common salt—or of chlorine and soda, in any other state of combination—it will be unnecessary to add this substance, or if added, it will produce no beneficial effect. If, on the other hand, the soil contain little, and has no natural source of supply, the addition of salt may cause a considerable increase in the crop.

Now there are certain localities in which we can say before hand that common salt is likely to be abundant in the soil. Such are the lands that lie along the sea-coast, or which are exposed to the action of prevailing sea winds. Over such districts the spray of the sea is constantly borne by the winds and strewed upon the land, or is lifted high into the air, from which it descends afterwards in the rains.* This consideration, therefore, affords us the important practical rule in regard to the application of common salt—*that it is most likely to be beneficial in spots which are remote from the sea or are sheltered from the prevailing sea winds.*

It is an interesting confirmation of this practical rule that nearly all the successful experiments above detailed, were made in localities more or less remote from the sea, while most of the failures on record were experienced near the coast. This consideration, it may be hoped, will induce many practical men to proceed with more confidence in making trial of its effects on inland situations. It is very desirable that the value of this practical rule, which I suggested to you in a former lecture (Part II. p. 288), should be put to a rigorous test.*

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* Dr. Madden has calculated that the quantity of rain which falls at Penicuick in a year, brings down upon each acre of land in that neighbourhood, more than 600 lbs. weight of common salt. This would be an enormous dressing were it all to remain upon the land. Heavy rains, however, probably carry off more from the soil than they impart to it. It is the gentle showers that most enrich the fields with the saline and other matters they contain.

2°. But some plants are more likely to be benefitted by the application of common salt than others. This may be inferred from the fact that certain species are known to flourish by the sea-shore, and where they grow inland to select such soils only as are naturally impregnated with much saline matter. Observations are still wanting to show which of our cultivated crops is most favoured by common salt. It is known, however, that the grass of salt marshes is peculiarly nourishing, and is much relished by cattle, and that the grass lands along various parts of our coast produce a herbage which possesses similar properties. It is said also that the long *tussack grass* which covers the Falkland Islands luxuriates most when it is within the immediate reach of the driving spray of the southern sea. It may well be, therefore, that among our cultivated crops one may delight more in common salt than another,—and if we consider how much alcaline matter is contained in the tops and bulbs of the turnip and the potato, we are almost justified in concluding that generally common salt will benefit green crops more than crops of corn, and that it will promote more the development of the leaf and stem than the filling of the ear.

If this be so we can readily understand how a soil may already contain abundance of salt to supply with ease the wants of one crop, and yet too little to meet readily the demands of another crop. The application of salt to such a soil will prove a failure or otherwise, according to the kind of crop we wish to raise.

3°. Failures have sometimes been experienced also on repeating the application of salt to fields on which its first effects were very favourable. In such cases it may be presumed that the land has been already supplied with salt, sufficient perhaps, for many years' consumption,—and that it now requires the application of some other substance.

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* A number of failures are described in the sixth volume of the "*Transactions of the Highland and Agricultural Society.*" Dr. Madden has recently shown that to nearly all these cases the above principle applies—the farms on which they were tried being more or less freely exposed to the winds from the east or west sea.—*Quarterly Journal of Agriculture, Sept.*, 1842, (p. 574).

If it be desired, experimentally, to ascertain whether the land already contains a sufficient supply of common salt, the readiest method is to collect half a pound of the soil in dry weather, to wash it well with a pint or two of cold distilled water, and then to filter through paper, or carefully to pour off the clear liquid after the whole of the soil has been allowed to subside. A solution of nitrate of silver (common lunar-caustic of the shops) will throw down a white precipitate, becoming purple in the sun, which will be more or less copious according to the quantity of salt in the soil. If this precipitate be collected, dried in an oven, and weighed, every 10 grains will indicate very nearly the presence of 4 grains of common salt. The quantity of this precipitate to be expected, even from a soil rich in common salt, is, however, very small. If half a pound of the dry soil yield a single grain of salt, an acre should contain about 1000 lbs. of salt where the soil is 12 inches deep—where it has a depth of only 6 inches it will contain nearly 500 lbs. in every acre.

8°. *Chlorides of Calcium and Magnesium.*—These compounds are rejected in large quantities as a refuse in some of our chemical manufactories—and they are contained, especially the latter, in considerable abundance in the refuse liquor of our salt pans. They have both been shown to be useful to vegetation (Appendix, p. 12), and where they are easily to be obtained, they are deserving of further trials. Like common salt, it is generally in inland situations that they are fitted to be most useful. Where salt springs are found in the interior of Germany, the refuse obtained by boiling down the mother liquors after the separation of the salt has been often applied with advantage to the land.

Theory of the action of these chlorides.—Common salt and the chlorides of calcium are not unfrequently found in the sap of plants—they may be supposed, therefore, to enter into the roots without necessarily undergoing any previous decomposition. But we have already seen (Part I.

p. 136) that the green leaves under the influence of the sun, have the power of decomposing common salt—and no doubt the other chlorides also—and of giving off their chlorine into the surrounding air. When they have been introduced into the sap therefore, by the roots, the plant first appropriates so much of the chlorine they contain as is necessary for the supply of its natural wants and evolves the rest. When common salt is thus decomposed, soda remains behind in the sap, and this is either worked up into the substance of the plant, or performs one or other of those indirect functions I have already explained to you (Part III. p. 47) when illustrating the probable action of potash and soda upon the vegetable economy. When the other chlorides (of calcium or magnesium) are decomposed, lime or magnesia remains in the sap, and is in like manner either used up directly in the formation of the young stem and seed, or is employed indirectly in promoting the chemical changes that are continually going on in the sap. The living plant, when in a healthy state, is probably endowed with the power of admitting into its circulation, and of then decomposing and retaining so much only of these several chlorides, or of their constituents, as is fitted to enable its several organs to perform their functions in the most perfect manner.

In the soil itself, in the presence of organic matter of animal and vegetable origin, common salt is fitted to promote certain chemical changes, such as the production of alcaline nitrates—and probably silicates—by which the growth of various kinds of plants is in a greater or less degree increased. In the soil, also, from their tendency to deliquesce, or run into a liquid, all these chlorides attract water from the air, and thus help to keep the soil in a moister state. When applied in sufficient quantity they destroy both animal and vegetable life, and have, in consequence, been often used with advantage for the extirpation of weeds, and for the destruction of grubs and other vermin that infest the land.

9°. *Phosphate of Lime and Earth of Bones.*—The cattle that graze in our fields derive, as you know, all the earthy materials of which certain parts of their bodies consist from the vegetables on which they feed. These vegetables again must derive them from the soil. Thus the earth of bones, or the phosphoric acid and lime of which it consists (Part II. p. 289), must exist in the soil on which nutritive plants grow, and it must occasionally occur that a soil will be deficient in these substances, and will, therefore, supply them with difficulty to the crops it rears. The benefit which in this country is so often experienced from the use of bones as a manure, has been ascribed, *in part*, to the supply of bone-earth, with which it enriches the land.* It is not, however, to be inferred from this that wherever bones are useful, the application of bone-earth alone—in the form of burned bones, or of the native phosphate of lime (Part II. p. 293),—will necessarily prove advantageous also. Burned bones were formerly employed in England, but the practice has gradually fallen into disuse, and the same is, I believe, the case in Germany. This is no proof, however, that the native phosphate of Estremadura—already, it is said, imported into Ireland for agricultural purposes, —would not benefit many soils if applied in the state of a sufficiently fine powder. Until carefully conducted experiments, however, shall have been made, and the numerical results precisely ascertained, it would be improper to incur much risk either in bringing this substance to our shores or in applying it to our fields.

10°. *Silicates of potash and soda.*—These compounds which have been already described (Part II. p. 304), are supposed to act an important part in the growth of the grasses, and of the corn-bearing plants, by supplying, in a soluble state to the roots, the silica which is so necessary to the strength of their stems. This supposition has been strengthened by the results of some experiments made by Lampadius, who found a solution of silicate of potash to produce remarkable effects upon Indian corn and upon rye.† It is possible to manufacture them at a cheap rate, and it would be desirable to ascertain by further trials how far the employment of these compounds, as artificial manures can be safely recommended or adopted with the hope of remuneration.*

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* See Appendix, p. 11.

† *Lehre von den mineralischen Dungmitteln*, p. 25, (1833).

11°. *Salts of Ammonia.*—There is reason to believe that ammonia in every state of combination is fitted, in a greater or less degree, to promote the growth of cultivated plants. None of its compounds, however, are known to occur any where in nature in such quantity as to be directly available in practical agriculture, and only a very few can be produced by art at so low a price as to admit of their being used with profit.

a. Sulphate of ammonia.—An impure sulphate is manufactured by adding sulphuric acid to fermented urine, or to the ammoniacal liquor of the gas works, and evaporating to dryness. When prepared from urine, it contains a mixture of those phosphates which exist in urine, and which ought to render it more valuable as a manure. The gas liquor yields a sulphate which is blackened by coal tar—a substance which, while not injurious to vegetation, is said to be noxious to the insects that infest our corn fields. In any of these economical forms this salt has been found to promote vegetation; but accurate experiments are yet wanting to show in what way it acts—whether in promoting the growth of the green parts or in filling the ear, or in both—to what kind of crops it may be applied with the greatest advantage—and what amount of increase may be expected from the application of a given weight of the salt. It is from the rigorous determination of such points that the practical farmer will be able to deduce the soundest practical precepts, and at the same time to assist most in the advancement of theoretical agriculture.

The crystallized sulphate of ammonia is soluble in its own weight of water. 100 lbs. contain about 35 lbs. of ammonia, 53 lbs. of acid, and 12 lbs. of water. It may be applied at the rate of from 30 lbs. to 60 lbs. per acre.

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* I have been informed by Dr. Playfair that a number of experiments with a soluble silicate of soda, manufactured at Manchester, have this summer (1842) been made at his suggestion, the results of which will, no doubt, prove very interesting.

b. Sal-Ammoniac or Muriate of Ammonia.—This salt, in the pure state in which it is sold in the shops, is too high in price to be economically employed by the practical farmer. An impure salt might, however, be prepared from the gas liquor, which could be sold at a sufficiently cheap rate to admit of an extensive application to the land.* The only numerical results from the use of this salt with which I am acquainted, are those given by Mr. Fleming, who applied it at the rate of 20 lbs. per acre to wheat on a heavy loam, and to winter rye, on a tilly clay, both after potatoes, and obtained the following increase of produce per acre:—

	Grain.	Straw.
Rye, undressed, - - -	14 bushels.	36½ cwt.
- - - dressed, - - - - -	19 - - - - -	43½ - - -
Increase - - - - - -	5 bushels.	7 cwt.

Wheat, undressed,	25 bushels,	each 61 lbs.
- - - - dressed, - -	26⅘ bushels,	each 62 lbs.
Increase - - -	1⅘ bushels.	

The increase in these experiments was not very large, but the quantity of sal-ammoniac employed was probably not great enough to produce a decided effect. It is a valuable fact for the farmer, however, and not uninteresting in a theoretical point of view, that a part of the same wheat field, dressed with 1½ cwt. of common salt per acre, *gave a produce of* 40 *bushels of grain* (see Appendix, p. 29.)

c. Carbonate of Ammonia—is obtained in an impure form by the distillation of horns, hoofs, and even bones. In this impure form it is not generally brought into the market, but in this state it might possibly be afforded at so low a price as to place it within the reach of the practical farmer. It is supposed by some that this carbonate is too volatile—or rises too readily in the form of vapour—to be economically applied to the land. In the form of a weak solution, however, put on by a water cart, or in moist showery weather simply as a top-dressing, especially to grass lands and on light soils, it may be safely recommended where it can be cheaply procured.

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* By mixing, for example, the waste muriatic acid, or the waste chloride of calcium, with the gas liquor, and evaporating the mixture to dryness.

d. Ammoniacal Liquor.—This is proved by the success which has in many localities been found to attend the application of the ammoniacal liquor of the gas works. This liquid holds in solution a variable quantity of sulphate of ammonia and of sal-ammoniac,[*] but in general it is richest in the carbonate of ammonia.

The strength of the liquor varies in different gas works; chiefly according to the kind of coal employed for the manufacture of the gas. One hundred gallons may contain from 20 lbs. to 40 lbs. of ammonia, in one or other of the above states of combination. No precise rule, therefore, can be given for the quantity which ought to be applied to the acre of land, but as the application of a larger quantity can do no harm, provided it be sufficiently diluted with water, one hundred gallons may be safely put on at first, and more if experience should afterwards prove it to be useful.

On grass and clover, upon a heavy moist loam, Mr. Bishop applied 105 gallons an acre, diluted with 500 gallons of water, and obtained, of hay, from the

Undressed,	½ lb. per square yard,	or 20½ cwt. per acre.
Dressed,	1½ lb.	or 61½ cwt. . . .
	—	—
Increase,	1 lb.	or 41 cwt.[†] . . .

The increase here is so very great that further trials with this liquor—hitherto, in most country towns at least, allowed to run to waste—cannot be too strongly recommended. On the dressed part, according to Mr. Bishop, the Timothy grass was particularly luxuriant.

These experiments with the gas liquor show, as I have said, that impure carbonate of ammonia may be safely applied to the land without any previous preparation. If it is wished, however, to fix it or to render it less volatile—which in warm and dry seasons may sometimes be desirable—this may be effected by mixing it with powdered gypsum, in the proportion of 1 lb. to each gallon of the ammoniacal liquor, or by adding directly sulphuric acid, or the waste muriatic acid of the alcali works.*

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[*] Each gallon of the ammoniacal liquor of the Manchester gas works is said to contain 2 ounces of *Sal-Ammoniac*. In these works the Cannel coal of Wigan is employed.

[†] *Prize Essays of the Highland Society*, xiv., p. 359.

e. Nitrate of Ammonia.—If it be correct that those substances act most powerfully as manures which are capable of yielding the largest quantity of nitrogen to plants, the nitrate of ammonia ought to promote vegetation in a greater degree than almost any other saline substance we could employ. According to the experiments of Sir H. Davy,† however, this does not appear to be the case, though Sprengel has found it more efficacious than the nitrates either of potash or of soda. This question as to the relative action of the nitrate of ammonia is very interesting theoretically, but it directly concerns practical agriculture very little, since the high price of this salt is likely to prevent its being ever employed in the ordinary operations of husbandry.

f. Special action of the different Salts of Ammonia.—The theory of the action of ammonia itself upon vegetation I have in a former lecture (Part I. p. 247) endeavoured to explain to you. But the special action of the several *saline* compounds of ammonia above described, will depend upon the qualities of the acid with which it may be in combination.

The *sulphate* will partake of the action of the sulphates of potash, soda, or lime (gypsum),—in so far as it may be expected to exhibit a more marked effect upon the leguminous than upon the corn crops, and upon the produce of grain than on the growth of the leaves and the stem. This special action may be anticipated from the sulphuric acid it contains. And if this reasoning from analogy be correct, we should expect the sulphate of ammonia to rank among the most useful of manures—since the one constituent (ammonia) will promote the general growth of the plant, while the other will expend its influence more in the filling of the ear.

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* 100 gallons thus saturated with acid will convey to the soil *about* 100 lbs. of sulphate of ammonia or of sal-ammoniac.

† Davy's *Agricultural Chemistry*, Lecture VII.

The *nitrate* again has been found to act more upon the crops of corn than upon the leguminous plants and clovers (Sprengel)—a result which is to be explained by the absence of sulphuric acid, which appears to aid especially in the development of the latter class of plants.

On this subject, however, experiments are too limited in number, in general too inaccurately made, and our information in consequence too scanty to enable us as yet to arrive at satisfactory conclusions.

12°. *Mixed Saline Manures.*—The principle already so frequently illustrated, that plants require for their rapid and perfect development a sufficient supply of a considerable number of different inorganic substances, will naturally suggest to you that in our endeavours to render a soil productive, or to increase its fertility, we are more likely to succeed if we add to it a mixture of several of those substances, than if we dress it or mix it up with one of them only. This theoretical conclusion is confirmed by universal experience.

Nearly all the natural manures, whether animal or vegetable, which are applied to the land, contain a mixture of saline substances, each of which exercises its special effect upon the after-crop—so that the final increase of produce obtained by the aid of these manures, must be ascribed not to the single action of one of their constituents, but to the joint action of all. An important practical problem, therefore, propounded by scientific agriculture in its present state is—what mixtures of saline substances are most likely to be *generally* useful, what others *specially* useful to this or to that crop? The complete solution of this problem will require the joint aid of chemical theory and of agricultural experiment,—of experiments often varied and probably long continued. But that we may finally expect to solve it, will appear from what has already been accurately observed in regard to the effect of certain artificial mixtures upon some of our cultivated crops. Thus—

a. Mixture of Nitrate with Sulphate of Soda.—If, instead of dressing young potatoes with nitrate or with sulphate of soda alone (Part III. p. 45), we employ a mixture of the two, the growth of the plant is much more promoted and the crop of potatoes much more largely increased. Thus Mr. Fleming (in 1841) applied to his potato crop a mixture of equal weights of nitrate and of dry sulphate of soda in the proportion of 200 lbs. of the mixture to the imperial acre, with the following remarkable result:—

Undressed, - - - 66 bolls, each 5 cwt., per acre.
Dressed, - - - - 107 bolls.

Increase, - - - 41 bolls,* or 10 tons per acre!

The stems also were six and seven feet high. The addition of nitrate of soda to a portion of the same field gave a produce of only 80 bolls. Similar effects, of which, however, I have not yet obtained the numerical results, have been observed on the same crop in various localities during the present season (1842).

The effect of this one artificial mixture holds out the promise of much good hereafter to be obtained by the judicious trial of other mixtures—probably of a greater number of substances—upon all the crops we are in the habit of raising for food.

b. Wood ashes.—This opinion is strengthened by the effects which have almost universally been found to follow the use of wood ashes and of the ash of other vegetables in the cultivation of the land.

The quality of the ash left by plants when burned varies as we have already had occasion to remark (Part II. p. 329) with a variety of circumstances. It always consists, however, of a mixture in variable proportions of carbonates, silicates, sulphates, and phosphates of potash, soda, lime, and magnesia, with certain other substances present in smaller quantity, yet more or less necessary, it may be presumed, o vegetable growth. Thus according to Sprengel the ash of the red beech, the oak, and the Scotch fir (*pinus sylvestris*) consists of

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* See Appendix, p. 32.

	Red Beech.	Oak.	Scotch Fir.	Pitch Pine. (Berthier.)
Silica	5·52	29·95	6·59	7·50
Alumina	2·33			
Oxide of Iron	3·77	8·14	17·03	11·10
Oxide of Manganese	3·85			2·75
Lime	25·00	17·38	23·18	13·60
Magnesia	5·00	1·44	5·02	4·35
Potash	22·11	16·20	2·20	14·10
Soda	3·32	6·73	2·22	20·75
Sulphuric Acid	7·64	3·36	2·23	3·45
Phosphoric Acid	5·62	1·92	2·75	0·90
Chlorine	1·84	2·41	2·30	——
Carbonic Acid	14·00	15·47	36·48	17·50
	100	100	100	96·0

The composition of these different kinds of ash is very unlike—that of the pitch pine for example being greatly richer in potash and soda, and poorer in lime and phosphoric acid, than that of the Scotch fir—while the beech is richer than any of the others in potash and lime and in the sulphuric and phosphoric acids. The several effects of different kinds of wood ashes when applied to the land will therefore be different also.

In this country wood ashes are largely employed in many districts, mixed with bone dust, as a manure for turnips, and often with great success. As much as 15 bushels (7½ cwt.) of ashes are drilled in per acre with 15 bushels (6 cwt.) of bones. The large quantity of alcali present in the turnip crop (Part II. p. 322) may be supposed to explain the good effects which wood ashes have upon it, and may lead us to expect that they would in a similar degree increase the produce of the carrot and of the potato.*

* This inference has been verified by Mr. Wharton, of Dryburn, who has obtained an excellent crop of potatoes from newly ploughed out land by manuring with wood ashes only.

The *immediate* benefit of wood ash is said to be most perceptible upon leguminous plants (Sprengel) such as lucerne, clover, peas, beans, and vetches. As a top dressing to grass lands it roots out the moss and promotes the growth of white clover. Upon red clover its effects will be more certain if previously mixed with one-fourth of its weight of gypsum. In small doses of two or three hundred weight (4 to 6 bushels) it may be safely applied even to poor and thin soils, but in large and repeated doses its effects will be too exhausting unless the soil be either naturally rich in vegetable matter, or be mixed from year to year with a sufficient quantity of animal or vegetable manure.

In so far as the immediate effect of wood ashes is dependent upon the soluble saline matter they contain, their effect may be immediate by a mixture of crude potash with carbonate and sulphate of soda, and a little common salt. The wood ash of this country contains only about one-fifteenth of its weight of soluble matter (Bishop Watson), so that the following quantity of such a mixture would be nearly equal in efficacy to the saline matter of *one ton* of wood ash.

Crude Potash	60 lbs. at a cost of	15s.
Crystalized Carbonate of Soda	60	7s.
Sulphate of Soda	20	2s.
Common Salt	20	
	160 lbs.	24s.

Where the wood ash costs only a shilling a bushel (or £2 a ton), it would obviously be more economical to employ this mixture, were the efficacy of wood ashes dependent solely upon the soluble saline matter they are capable of yielding on the first washing with water. But they contain also a greater or less quantity of imperfectly burned carbonaceous matter, the effect of which upon vegetation cannot be precisely estimated, and a large proportion—nine-tenths, perhaps, of their whole weight—

of insoluble carbonates, silicates, and phosphates of potash, lime, and magnesia, which are known more *permanently* to influence the fertility of the land to which they are applied.*

c. Washed or lixiviated wood ashes.—In countries where wood ashes are washed for the manufacture of the pot and pearl ash of commerce (Part II. p. 274), this insoluble portion collects in large quantities. It is also present in the refuse of the soap makers, where wood ash is employed for the manufacture of soft soap. The composition of this insoluble matter varies very much, not only with the kind of wood from which the ash is made, but also with the *temperature* it is allowed to attain in burning. The former fact is illustrated by the following analyses made by Berthier, of the insoluble matter left by the ash of five different species of wood carefully burned by himself:—

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* Some discussion has lately arisen in America (*Silliman's Journal*, xlii. p. 165, and xliii. p. 80), in regard to the fact, in itself sufficiently interesting, that wood ashes, when thrown together in heaps, not unfrequently take fire, becoming red hot throughout their whole mass, and sometimes occasioning serious accidents. Such ashes always contain a quantity of minutely divided carbonaceous matter, which, like the impalpable charcoal powder of the gunpowder manufactories, may have the property of absorbing much air into its pores, and of thus undergoing a spontaneous elevation of temperature. I throw it out, however, as a more probable conjecture, that during the combustion of the wood a portion of the potash has been decomposed by the charcoal, and converted into potassium (potash consisting of potassium and oxygen, Part II. p. 276). When exposed to the air and to moisture this potassium gradually absorbs oxygen and spontaneously burns, again forming potash. That such a decomposition may take place where wood or other vegetable matter is burned with little access of air will readily be granted, but it is not so obvious that it *can* take place in an open fire. But even in an open fire, or in an open capsule, particles of potassium may remain in the pores of the unburned charcoal, or more frequently may be covered over with a glaze of melted potash, by which further combustion will be prevented. That this really does happen any one must have satisfied himself who has been in the habit of burning vegetable substances for the purpose of determining the proportion of ash they leave. The glaze of melted alcaline matter often renders the complete combustion a very difficult and tedious matter. That potassium is formed during this process is rendered further probable by the observation that the quantity of potash obtained from wood or other vegetable ash is less when the wood has been burned at a high than at a low temperature. The potassium, which is volatile, may have been dissipated in vapour.

It is probable that a spontaneous combustion similar to that observed in America may occasionally take place in the heaps of ashes left to stand upon our fields after paring and burning—and hence probably has arisen the practical rule, to spread the ashes as soon as possible after the burning is finished. If allowed to remain they are said "*to take hold of the land*," and when it is of clay, to burn it into brick. An instance of such combustion is mentioned as having occurred at Chatteris, in the Isle of Ely, where an entire common was burned 16 or 18 inches deep, down to the very gravel. —See *British Husbandry, II.*, p. 350.

	Oak.	Lime.	Birch.	Pitch Pine.	Scotch Fir.	Beech.
Silica - - - - -	3·8	2·0	5·5	13·0	4·6	5·8
Lime - - - - -	54·8	51·8	52·2	27·2	42·3	42·6
Magnesia - - -	0·6	2·2	3·0	8·7	10·5	7·0
Oxide of Iron - -	—	0·1	0·5	22·3	0·1	1·5
Oxide of Manganese	—	0·6	3·5	5·5	0·4	4·5
Phosphoric Acid -	0·8	2·8	4·3	1·8	1·0	5·7
Carbonic Acid - -	39·6	39·8	31·0	21.5	36·0	32·9
Carbon - - - -	—	—	—	—	4·8	—
	99·6	100	100	100	99·7	100

The numbers in these several columns differ very much from each other, but the constitution of the insoluble part of the ash he obtained probably differed in every case from that which would have been left by the ash of the same wood burned on the large scale, and in the open air. This is to be inferred from the total absence of potash and soda in the lixiviated ash—while it is well known that common lixiviated wood ash contains a notable quantity of both. This arises from the high temperature at which wood is commonly burned, causing a greater or less portion of the potash and soda to combine with the silica, and to form insoluble silicates which remain behind along with the lime and other earthy matter, when the ash is washed with water. It is to these silicates as well as to the large quantity of lime, magnesia, and phosphoric acid it contains, that common wood-ash owes the more *permanent* effects upon the land, which it is known to have produced. When the rains have washed out or the crops carried off the more soluble part from the soil, these insoluble compounds still remain to exercise a more slow and enduring influence upon the after-produce.

Still from the absence of this soluble portion, the action of lixiviated wood-ash is not so apparent and energetic, and it may therefore be safely added to the land in much larger quantity. Applied at the rate of two tons an acre, its effects have been observed to continue for 15 or 20 years. It is most beneficial upon clay soils, and is said especially to promote the growth of oats.

I am not aware that in any part of the British Islands this refuse ash is to be obtained in large quantity, but in North America much of it is thrown away as waste, which might be advantageously restored to the land on which the wood had grown.

d. Kelp is the name given in this country* to the ash left by marine plants when burned. It used to be extensively prepared in the Western Islands, but the low price at which carbonate of soda can now be manufactured has so reduced the price and the demand for kelp as almost to drive it from the market. As a natural mixture, however, which can now be obtained at a cheap rate (about £3 a ton), and which has been proved to be useful to vegetation in a high degree,† it is very desirable that accurate experiments should be instituted with the view of determining the precise extent of its action, as well as the crops and soils to which it can be most advantageously and most economically applied.

Like wood ashes, kelp varies in composition with the species and age of the marine plants (sea weeds), from which it is prepared, and like them also it consists of a soluble and insoluble portion. Two samples from different localities in the Isle of Sky, analyzed by Dr. Ure,‡ consisted of—

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* In Brittany and Normandy it is called *varec*, while that of Spain is known by the name of *barilla*.

† *Prize Essays of the Highland Society*, vol. 1 and 4.

‡ *Dictionary of Arts and Manufactures*, p. 726.

SOLUBLE PORTION.	Heisker.	Rona.	Normandy Gay Lussac.
Carbonate of Soda with Sulphuret of Sodium	8·5	5·5	—
Sulphate of Soda	8·0	19·0	—
Common Salt	36·5	37·5	56·0
Chloride of Potassium			25·0
	53·0	62·0	
INSOLUBLE PORTION.			
Carbonate of Lime	24·0	10·0	—
Silica	8·0	—	—
Alumina and Oxide of Iron	9·0	10·0	—
Gypsum	—	9·5	—
Sulphur and loss	6·0	8·5	—
	100	100	

Besides these constituents, however, the soluble portion contains iodide of potassium or sodium in variable quantity, and the insoluble more or less of potash and soda in the state of *silicates*.

Kelp may be applied to the land in nearly the same circumstances as wood-ash—but for this purpose it would probably be better to burn the sea-weed at a lower temperature than is usually employed. By this means, being prevented from melting, it would be obtained at once in the state of a fine powder, and would be richer in potash and soda.

It might lead to important results of a practical nature, were a series of *precise* experiments made with this finely divided kelp as a manure†—especially in inland situations—for though the variable proportion of its constituents will always cause a degree of uncertainty in regard to the action of the ash of marine plants—yet if the quantity of chloride of potassium it contains be on an average nearly as great as is stated above in the analysis of Gay Lussac—

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† For some other suggestions on this subject, I beg to refer the reader to the *Prize Essays and Transactions of the Highland and Agricultural Society*, xiv., p. 508.

kelp will really be the cheapest form in which we can at present apply potash to the land.

e. Straw Ashes.—The ashes obtained by burning the straw of oats, barley, wheat, and rye, contain a natural mixture of saline substances, which is exceedingly valuable as a manure to almost every crop. The proportion of the several constituents of this mixture, however, is different, according as the one or the other kind of straw is burned. Thus, 100 parts of each variety of ash—in the samples analyzed by Sprengel*—consisted of—

	Oats.	Barley.	Wheat.	Rye.	Rape.
Potash - - - -	15·2	3·4	0·6	1·2	18·8
Soda - - - -	trace.	0·9	0·8	0·4	11·2
Lime - - - -	2·6	10·5	6·8	6·4	16·9
Magnesia - - -	0·4	1·4	0·9	0·4	3·1
Silica - - - -	80·0	73·5	81·6	82·2	2·1
Alumina - - - -	0·1	2·8	2·6	0·9	2·3
Oxide of Iron - -	trace.	0·2			
Oxide of Manganese	trace.	0·3			
Phosphoric Acid -	0·2	3·5	4·8	1·8	9·9
Sulphuric Acid -	1·4	2·2	1·0	6·1	13·3
Chlorine - - -	0·1	1·3	0·9	0·6	11·4
Carbonic Acid - -	—	—	—	—	11·0
	100	100	100	100	100

The most striking differences in the above table are the comparatively large quantity of potash in the oat straw—of lime in that of barley—of phosphoric acid in that of wheat—of sulphuric acid in that of rye—and of all the saline substances in rape straw. These differences are not to be considered as constant, nor will the numbers in any of the above columns represent correctly the composition of the ash of any variety of straw we may happen to burn (Part II., p. 329), but they may be safely depended upon as showing the general composition of such ashes, as well as the general differences which may be expected to prevail among them.

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* Sprengel, *Chemie* II.

That such ashes should prove useful to vegetation might be inferred not only from their containing many saline substances which are known to act beneficially when applied to the land, but from the fact that they have actually been obtained from vegetable substances. If inorganic matter be necessary to the growth of wheat, then surely the mixture of such matters contained in the ash of wheat straw is more likely than any other we can apply to promote the growth of the young wheat plant. A question might even be raised whether or not in some soils, rich in vegetable matter, the ash alone would not produce as visible an effect upon the coming crop, as the direct application of the straw, either in the dry state, or in the form of rotted farm-yard manure. And this question would seem to be answered in the affirmative, by the result of many trials of straw ashes, which have been made in Lincolnshire. In this county the ash of five tons of straw has been found superior in efficacy to ten tons of farm-yard manure.* This is perfectly consistent with theory, yet as vegetable matter appears really essential to a fertile soil, and as the quantity of this vegetable matter is lessened in some degree by every corn crop we raise, it cannot be good husbandry to manure for a succession of rotations with saline substances only. The richest soil by this procedure must ultimately be exhausted. On the other hand, where much vegetable matter exists, and especially what is usually called *inert* vegetable matter, it may be an evidence of great skill in the practical farmer to apply *for a time*, the ashes only, of his straw—or some other saline mixture to his land.

The practice of burning the stubble on a windy day has been found in the East Riding of Yorkshire, to produce better clover, and to cause a larger return of wheat†—for this purpose, however, the stubble must be left of considerable length. In Germany, rape straw—which the above table shows to be so rich in saline and earthy matter, and, therefore, exhausting to the land—is spread over the field and burned in a similar manner. The destruction of weeds and insects which attends this practice, is mentioned as one of its collateral advantages.*

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* *Survey of Lincolnshire*, p. 304, quoted in British Husbandry, II., p. 334.

† *British Husbandry*, II., p. 333.

In the United States, where, according to Captain Barclay, the straw is burned merely in order that it may be got rid of,† it would cost little labour to apply the ash to the soil from which the straw was reaped, while it would certainly enlarge the future produce—and in Little Russia where from the absence of wood the straw is universally burned for fuel, and the ashes afterwards consigned to the nearest river, the same practice might be beneficially adopted. However fertile, and apparently inexhaustible, the soils in these countries may appear, the time must come when the present mode of treatment will have more or less exhausted their productive powers.

It is not advisable as I have already said, wholly to substitute the ash for the straw in ordinary soils, or in any soils for a length of time, yet that it may be partially so substituted with good effect—or that straw ashes will alone give a large increase of the corn crop, and therefore should never be wasted—is shown by the following comparative experiments, conducted, as such experiments should be, during an entire rotation of four years. The quantity of manure applied, and the produce per imperial acre were as follows :—

	No Manure.	15 cwt. barley straw burned on the ground.	8 tons stable dung in the straw state.	2 tons of rotten dung, eight months old.
1°. Turnips	22 lbs.	8⅓ cwt.	18¾ cwt.	16⅛ cwt.
2°. Barley	14¾ bush.	30¼ bush.	30½ bush.	36¾ bush.
3°. Clover	8 cwt.	18 cwt.	20 cwt.	21 cwt.
4°. Oats	32 bush.	18 bush.	38 bush.	40 bush.

The kind of soil on which this experiment was made is not stated,‡ but it appears to show, as we should expect, that the effects of straw ash are particularly exerted in promoting the growth of the corn plants and grasses which contain much siliceous matter in their stems—in short, of plants similar to those from which the ash has been derived.

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* Sprengel, *Lehre vom Dünger*, p. 355.

† *Agricultural Tour in the United States*, pp. 42 and 54.

‡ *British Husbandry* II., p. 248.

Theory of the action of straw ash.—That it should especially promote the growth of such plants appears most natural if we consider only the source from which it has been obtained, but it is fully explained by a further chemical examination of the ash itself. The soluble matter of wood ash *in general* contains but a small quantity of silica—while that part of the straw ash which is taken up by water contains very much. Thus a wheat ash analyzed by Berthier contained of

	PER CENT.
Soluble salts	19
Insoluble matter	81
	100

and that which was dissolved by water consisted of

	PER CENT.
Silica	35
Chlorine	13
Potash and soda	50
Sulphuric acid	2
	100

so that it was a mixture of *soluble* silicates and chlorides with a little sulphate of potash and soda. These soluble silicates will find an easy admission into the roots of plants, and will readily supply to the young stems of the corn plants and grasses the silica which is indispensable to their healthy growth.

f. Turf or peat ashes, obtained by the burning of peat of various qualities, are also applied with advantage to the land in many districts. They consist of a mixture in which gypsum is usually the predominating useful ingredient—the alcaline salts being present in very small proportion. Of ashes of this kind those made in Holland, and generally distinguished by the name of Dutch ashes, are best known, and have been most frequently analyzed. The following table exhibits the composition of some varieties of ashes from the peat of Holland and from the heath of Luneburg, examined by Sprengel:—

	Dutch Ashes, (grey.)			Luneburg Ashes, (reddish.)	
	Best quality.	Inferior quality.	Worst quality.	Good quality.	Producing little effect.
Silica - -	47·1	55·9	70·4	31·7	43·3
Alumina - -	4·5	3·5	4·1	5·1	9·7
Oxide of Iron -	6·6	5·4	4·1	17·7	19·3
Do. of Manganese	1·0	4·3	0·2	0·5	3·5
Lime - - -	13·6	8·6	6·1	31·9	7·1
Magnesia - -	4·9	1·6	3·9	1·0	4·6
Potash - -	0·2	0·2	0.1	0·1	——
Soda - - -	1·0	3·9	0·4	0·1	——
Sulphuric Acid -	7·2	6·4	3·4	6·2	Gypsum 0·2
Phosphoric Acid -	2·0	0·8	1·3	1·2	Phosph. of Lime 0·2
Chlorine - -	1·2	3·0	0·5	0·1	Common Salt 0·1
Carbonic Acid -	4·1	6·4	5·5	4·4	12·0
Charred Turf -	6·6	——	——	——	——
	100·0	100·0	100·0	100·0	100·0*

In the most useful varieties of these ashes it appears, from the above analyses that lime abounds—partly in combination with sulphuric and phosphoric acids, forming gypsum and phosphate of lime—and partly with carbonic acid, forming carbonate. These compounds of lime, therefore, may be regarded as the active ingredients of peat ashes.

Yet the small quantity of saline matter they contain is not to be considered as wholly without effect. For the Dutch ashes are often applied to the land to the extent of two tons an acre—a quantity which even when the proportion of alcali does not exceed one per cent., will contain 45 lbs. of potash or soda, equal to twice that weight of sulphates or of common salt. To the minute quantity of saline matters present in them, therefore, peat ashes may owe a portion of their beneficial influence, and to the almost total absence of such compounds from the less valuable sorts, their inferior estimation may have in part arisen.

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* Sprengel *Lehre vom Dunger*, p. 368, *et seq*.

In Holland, when applied to the corn crops, they are either ploughed in, drilled in with the seed, or applied as a top dressing to the young shoots in autumn or spring. Lucerne, clover, and meadow grass are dressed with it in spring at the rate of 15 to 18 cwt. per acre, and the latter a second time with an equal quantity after the first cutting. In Belgium the Dutch ashes are applied to clover, rape, potatoes, flax, and peas—but never to barley. In Luneburg the turf ash which abounds in oxide of iron is applied at the rate of 3 or 4 tons per acre, and by this means the physical character of the clay soils, as well as their chemical constitution, is altered and improved.

In England peat is in many places burned for the sake of the ashes it yields. Among the most celebrated for their fertilizing qualities, are the reddish turf ashes of Newbury, in Berkshire. The soil from beneath which the turf is taken abounds in lime, and the ashes are said to contain from one-fourth to one-third of their weight of gypsum.* They are used largely both in Berkshire and Hampshire, and are chiefly applied to green crops, and especially to clover.†

g. Coal ashes are a mixture of which the composition is very variable. They consist, however, in general, of lime often in the state of gypsum, of silica, and of alumina mixed with a quantity of bulky and porous cinders or half-burned coal. The ash of a coal from St. Etienne, in France, after all the carbonaceous matter had been burned away, was found by Berthier to consist of

	PER CENT.
Alumina, insoluble in acids, - -	62
Alumina, soluble - - - - -	5
Lime - - - - - -	6
Magnesia - - - - - - -	8
Oxide of Manganese - - -	3
Oxide and Sulphuret of Iron - -	16
	100

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* *British Husbandry*, II., p. 334.

† 50 bushels per acre (at 3d. a bushel, or 12s. 6d. an acre) increase the clover crop fully one-fifth.—Morton "*On Soils*," p. 170.

Such a mixture as this would no doubt benefit many soils by the alumina as well as by the lime and magnesia it contains; but in the English and Scotch coal ashes a small quantity of alcaline matter, chiefly soda,* is generally present. The constitution of the ash of our best coals, therefore, may be considered as very nearly resembling that of peat ash, and as susceptible of similar applications. When well burned, it can in many cases be applied with good effects as a top-dressing to grass lands which are overgrown with moss; while the admixture of cinders in the ash of the less perfectly burned coal produces a favourable physical change upon strong clay soils.

h. Cane Ashes.—I may allude here to the advantage which in sugar-growing countries may be obtained from the restoration of the cane ash to the fields in which the canes have grown. After the canes have been crushed in the mill they are usually employed as fuel in boiling down the syrup; and the ash, which is not unfrequently more or less melted, is, I believe, almost uniformly neglected—at all events is seldom applied again to the land. According to the principles I have so often illustrated in the present Lectures, such procedure must sooner or later exhaust the soil of those saline substances which are most essential to the growth of the cane plant. If the ash were applied as a top-dressing to the young canes, or put into the cane holes near the roots—having been previously mixed with a quantity of wood-ash, and crushed if it happen to have been melted—this exhaustion would necessarily take place much more slowly.

i. Crushed Granite.—We have already seen that the felspar existing in granite contains much silicate of potash and alumina. It is in fact a natural mixture, which in many instances may be beneficially applied, especially to soils which abound in lime. It is many years since Fuchs proposed to manufacture potash from felspar and mica by mixing them with quick-lime, calcining in a furnace, and then washing with water. By this means he said felspar might be made to yield one-fifth of its weight of potash.†

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* From the common salt with which our coal is so often impregnated.

† *Journal of the Royal Institution*, i., p. 184.

Mr. Prideaux has lately proposed to mix up crushed granite and quick lime, to slake them together, and to allow the mixture to stand in covered heaps for some months, when it may be applied as a top-dressing, and will readily give out potash to the soil. Fragments of granite are easily crushed when they have been previously heated to redness, and there can be little doubt, I think, that such a mixture as that recommended by Mr. Prideaux would unite many of the good effects of wood ashes and of lime.

k. Crushed Trap.—I need not again remind you of the natural fertility of decayed trap soils (Part II. pp. 385–6) and of the improvement which in many districts may be effected by applying them to the land. When granite decays, the potash of the felspar is washed out by the rains, and an unproductive soil remains—when trap decays, on the other hand, the lime by which it is characterized is not soon dissolved out, so that the soil which is produced is not only fertile in itself, but is capable of being employed as a fertilizing mixture for other soils. Thus when it is much decayed it is dug out from pits both in Cornwall and in Scotland, and is applied like marl to the land.

l. Crushed Lavas.—Of the fertile and fertilizing nature of the crushed or decayed lavas I have also already spoken to you (Part II. p. 388). In St. Michael's, one of the Azores, the natives pound the volcanic matter and spread it on the ground, where it speedily becomes a rich mould capable of bearing luxuriant crops. At the foot of Mount Etna, whenever a crevice appears in the old lavas, a branch or joint of an Opuntia (*Cactus Opuntia*—European Indian-Fig) is stuck in, when the roots insinuate themselves into every fissure, expand, and finally break up the lava into fragments. These plants are thus not only the means of producing a soil, but they yield also much fruit, which is sold as a refreshing food throughout all the towns of Sicily.*

These are all so many natural mineral mixtures of which we may either directly avail ourselves, or which we may imitate by art.

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* Decandolle quoted in the *Quart. Journ. of Agr.*, iv. p. 737.

Experiments with mixed manures.

NOTE.—As a valuable appendix to the preceding observations on mixed manures, I am permitted to insert the following very interesting results obtained during the present season, 1842, from experiments made on the estate of Mr. Burnet, of Gadgirth, near Ayr. The crop to which the several manures were applied was wheat of the *eclipse* variety, sown on the 29th of October, 1841, and reaped on the 15th of August last. The soil is a loam with subsoil of clay, tile drained and trenched ploughed. It had been in beans the previous year, and gave six quarters per acre, which were sold at 46s. a quarter. No manure had been applied with the bean crop, and except a good dose of lime before sowing the wheat, nothing but the saline mixtures mentioned below was applied with this latter crop.

Application per imperial acre.	PRODUCE PER IMP. ACRE.			Weight per bushel.	100 lbs. of grain produced of fine flour.
	Straw.	Grain.			
	cwt.	*bush.*	*lbs.*	*lbs.*	*lbs.*
Sulphate of Ammonia, 2 cwt.* Wood-ashes 4 cwt.	35¼	39	54	60	66½
Sulph. of Ammonia, 2 cwt. - - - Sulph of Soda, 2 cwt. - - - - Wood-ashes, 4 cwt.	44¾	49	6	60	63⅓
Sulph. of Ammonia, 2 cwt. - - - Common Salt, 2 cwt. Wood-ashes, 4 cwt.	45	49	0	60	65⅔
Sulph of Ammonia, 2 cwt. - - - Nitrate of Soda, 1 cwt. - - - Wood-ashes, 4 cwt.	44¼	48	20	59	54⅔
No application -	29¾	31	38	61½	76⅔

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* The sulphate of ammonia was prepared from urine, and, therefore, contained other admixtures (Part III. p. 72). The straw was strongest, coarsest, and longest in ripening, where this sulphate was applied. The two guanos produced little luxuriance, but the lots to which they were applied were soonest ripe.

The reader will observe here that though the first mixture produced a larger increase both of straw and grain, a still larger additional increase was caused by mixing with the substances of which it consisted either common salt or sulphate of soda or nitrate of soda. Each of these three substances produced nearly the same effect. The soda, therefore, more than the acid with which it was combined, must in these cases have acted beneficially. The comparatively small proportion of fine flour yielded by the *nitrated* wheat, and the comparatively large proportion obtained from that to which no application was made, are also highly deserving of notice.

Mr. Burnet has transmitted to me samples of the flour from these several growths of wheat, with a view of determining the relative proportions of gluten they contain. The result of this examination, which cannot fail to be interesting, will be given in a succeeding lecture—before which, however, I hope the whole of Mr. Burnet's experiments will be laid before the public.

It will be observed that Mr. Burnet has exercised a sound discretion in making and trying mixtures not hitherto specifically recommended. It is by the result of such varied experimental trials, made by intelligent practical men, on different soils and crops, and with mixtures of which *the constitution is exactly known*, that we shall be able hereafter to correct our theoretical principles—as well as to simplify and render more sure our general practice.*

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* While this sheet is going through the press, I am informed that the *silicate of potash*, referred to in Part III. p. 71, is now manufactured by the Messrs. Dymond, of London, and may be obtained from the London dealers at 56s. a cwt. I expect, also, that a silicate of soda will soon be brought into the market by the Messrs. Cookson's, of the Jarrow Alkali Works, at a much lower price. The *probable* efficacy of these substances, as manures, has, no doubt, been extolled too highly by some—their *real* efficacy, however, is well deserving of investigation. I shall insert in the Appendix No. VII. therefore, some suggestions for experiments with these substances, in the hope that during the ensuing spring, 1843, some experiments on the subject may be made.

LECTURE XVII.

Use of lime as a manure. Value of lime in improving the soil. Of the composition of common and magnesian lime-stones. Burning and slaking of lime. Changes which slaked lime undergoes by exposure to the air. Various *natural* states in which carbonate of lime is applied to the land. Marl—shell and coral sand,—lime-stone sand and gravel,—crushed lime-stone. Chemical composition of various marls, and shell and lime-stone sands. Their effects on the soil. Use of chalk. Is lime necessary to the soil? Exhausting effect of lime. Analogy between this action of lime and that of wood-ashes. Quantity of lime to be applied. Effects of an overdose. Form in which it may be most prudently used. When it ought to be applied in reference to the season—to the rotation—and to the application of manure. Its general and special effects on different soils and crops. Circumstances which influence its action. Length of time during which its effects are perceptible. Theory of the action of lime. Necessity and nature of the exhaustion which it sometimes produces. Sinking of lime into the soil. Why the application of lime must be repeated. Action of lime on living animals and vegetables. Suggestions of theory. Use of silicate of lime.

Having explained to you the action of the most important saline and mixed mineral substances which are or may be beneficially applied to the soil, I have now to draw your attention to the use of lime—the most valuable and the most extensively used of all the mineral substances that have ever been made available in practical agriculture. It has, and with much reason, been called "the basis of all good husbandry"—it well deserves, therefore, your most serious attention as practical men, and on my part the application of every chemical light by which its usefulness may be explained and your practice guided. This consideration also will justify me in dwelling upon it with some detail, and in illustrating separately the various points, both of theory and practice, which present themselves to us, when we study the history of its almost universal application to the soil.

§ 1. *Of the composition of common and magnesian lime-stones.*

1°. *Common lime-stones.*—Lime is never met with in nature except in a state of chemical combination (Part I. p. 40) with some other substance. That which is usually employed in agriculture is met with in the state of *carbonate*.

Carbonate of lime, or common lime-stone, consists of lime and carbonic acid, and, when perfectly pure and dry, in the following proportions:—

	per cent.	
Carbonic acid,	43·7	or one ton of pure dry carbonate of lime contains 11¼ cwts. of lime.
Lime, ...	56·3	
	100	

Limestones, however, are seldom pure. They always contain a sensible quantity of other earthy matter, chiefly silica, alumina, and oxide of iron, with a trace of phosphate of lime, sometimes of potash and soda, and often of animal or other organic matter. In lime-stones of the best quality the foreign earthy matter or impurity does not exceed 5 per cent. of the whole—while it is often very much less. The chalks and mountain lime-stones are generally of this kind. In those of inferior quality it may amount to 12 or 20 per cent., while many calcareous beds are met with in which the proportion of lime is so small that they will not burn into agricultural or ordinary building lime—refusing to slake or to fall to powder when moistened with water. Of this kind is the Irish *calp* and the lime-stone nodules which are burned for the manufacture of hydraulic limes or cements.* It is easy to ascertain the quantity of earthy matter in a lime-stone, by simply introducing a known weight of it into cold diluted muriatic acid and observing or weighing the part which, after 12 hours, refuses to dissolve or to exhibit any effervescence. It is to the presence of these insoluble impurities that lime-stones in general owe their colour, pure carbonate of lime being perfectly white.

* Thus that of Aberthaw contains about 86 of carbonate of lime and 11 of clay, &c.; that of Yorkshire 62 of carbonate of lime and 34 of clay; of Sheppy 66 of carbonate of lime and 32 of clay. These lime-stones are burned, and then crushed to an impalpable powder, which sets almost immediately when mixed up with water.

2°. ***Magnesian lime-stones.***—Though often nearly white, the magnesian lime-stones of our island are generally of a yellow colour. They cannot by the eye be distingushed from common lime-stones of a similar colour, but they are characterized by containing a greater or less proportion of carbonate of magnesia, which is more or less easily detected by analysis. Pure carbonate of magnesia consists of

	per cent.
Carbonic acid,	51·7
Magnesia, . .	48·3
	100

or one ton of pure dry carbonate of magnesia contains $9\frac{4}{5}$ cwts. of magnesia.

It contains, therefore, a considerable larger proportion of carbonic acid than is present in carbonate of lime.

Magnesian lime-stone is very abundant, is indeed the prevailing rock in many parts of England (Part II., p. 364), but the proportion of carbonate of magnesia it contains is very various in different localities. Even in the same quarry different beds contain very unlike proportions of magnesia, and are therefore more or less fitted for agricultural purposes. Thus several varieties of this lime-stone, examined by myself, from different parts of the county of Durham, contained the two carbonates in the following proportions :—

	Carbonate of Lime.	Carbonate of Magnesia.	Alumina, Oxide of Iron, and Phosphoric acid.	Insoluble matter.	
Garmondsway . . .	97·5	2·5	trace	trace	Hard compact gray.
Stony-gate	98·0	1·61	0·27	0·12	Crystalline fine grained yellow.
Fulwell	95·0	2·1	0·3	2·6	Honey-combed crystalline yellow.
Seaham (A)	96·5	2·3	0·2	1·0	Hard fine grained compact.
. . . . (B)	95·0	1·3	0·2	3·5	Hard porous brown.
Hartlepool	54·5	44·93	0·33	0·24	Oolitic yellow.
Humbledon Hill (A)	57·9	41·8	?	0·28	Perfect encrinal columns.
. . . . . . (B)	60·41	38·78	?	0·81	Consisting in part of encrinal columns.
Ferryhill	54·1	44·72	1·58	4·6	Yellowish compact.

Some of these varieties, as we see, contain very little carbonate of magnesia, and, therefore, are found to produce excellent lime for agricultural purposes—while in others this substance forms nearly one-half of the whole weight of the rock. Similar differences are found to prevail in almost every locality.

This admixture of magnesia in greater or less quantity is not confined to the lime-stones of the magnesian limestone formation properly so called. It is found in sensible quantity in certain beds of lime-stone in nearly every geological formation, and there are few natural lime-stones of any kind in which traces of it may not be discovered by a carefully conducted chemical examination.

The simplest method of detecting magnesia in a limestone is to dissolve it in diluted muriatic acid, and then to pour clear lime water into the filtered solution. If a light white powder fall, it is magnesia. The relative proportions in two lime-stones may be estimated pretty nearly by dissolving an equal weight of each, pouring the filtered solutions into bottles which can be corked, and then filling up both with lime water. On subsiding, the relative bulks of the precipitates will indicate the respective richness of the two varieties in magnesia.

§ 2. *Of the burning and slaking of lime.*

Burning.—When carbonate of lime or carbonate of magnesia is heated to a high temperature in the open air the carbonic acid they severally contain is driven off, and the lime or magnesia remains in the caustic state. When thus heated the carbonate of magnesia parts with its carbonic acid more speedily and at a lower temperature than carbonate of lime.

On the large scale this burning is conducted in lime kilns, one ton of good lime-stone yielding about 11 cwts. of *burned*, *shell*, *quick*, or *caustic* lime.

Slaking.—When this shell or quick-lime, as it is taken from the kiln, is plunged into water for a short time and then withdrawn, or when a quantity of water is poured upon it, heat is developed, the lime swells, cracks, gives off much watery vapour, and finally falls [illegible] a fine, bulky, more or less white powder. These appearances are more or less rapid and striking according to the quality of the lime, and the time that has been allowed to elapse after the burning, before the water was applied. All lime becomes difficult to slake when it has been for some time exposed to the air. When the slaking is rapid as in the rich limes, the heat produced is sufficient to kindle gunpowder strewed upon it, and the increase of bulk is from 2 to 3½ times that of the original lime shells. If the water be thrown on so rapidly or in such quantity as to chill the lime or any part of it, the powder will be gritty, will contain many little lumps which refuse to slake, will also be less bulky and less minutely divided, and therefore will be less fitted either for agricultural or for building purposes.

When quick-lime is left in the open air, or is covered over with sods in a shallow pit, it gradually absorbs water from the air and from the soil, and falls, though much more slowly, and with little sensible development of heat, into a similar fine powder. In the rich limes the increase of bulk may be 3 or 3½ times, in the poorer or such as contain much earthy matter, it may be less than twice.

Hydrate of Lime.—When quick-lime is thus slaked it *combines* with the water which is added to it, and becomes converted into a milder or less caustic compound, which among chemists is known by the name of *hydrate* of lime. This hydrate consists of

	per cent.	
Lime . . .	76	or one ton of pure burned lime becomes nearly 25 cwts. of slaked lime.
Water . .	24	
	100	

It is rare, however, that lime is so pure or so skilfully and perfectly slaked as to take up the whole of this proportion of water, or to increase quite so much as one-fourth part in weight.

Hydrate of Magnesia.—When calcined or caustic magnesia is slaked, it also combines with water, but without becoming so sensibly hot as quick-lime does, and forms a hydrate, which consists of

	per cent.	
Magnesia,	69·7	or one ton of pure burned magnesia becomes 28⅗ cwts. of hydrate.
Water, . .	30·3	
	100	

When magnesian lime is slaked, the fine powder which is obtained consists of a mixture of these two hydrates, in proportions which depend of course upon the composition of the original lime-stone.

An important difference between these two hydrates is, that the hydrate of magnesia will harden under water or in a wet soil in about 8 days—forming a hydraulic cement. Hydrate of lime will not so harden, but a mixture of the two in the proportions in which they exist in the Hartlepool, Humbledon, and Ferryhill lime-stones (Part III. p. 96), will harden under water, and form a solid mass. In the minute state of division in which lime is applied to the soil the particles, if it be a magnesian lime, will, in wet soils or in the event of rainy weather ensuing immediately after its application, become granular and gritty, and cohere occasionally into lumps, on which the air will have little effect. This property is of considerable importance in connection with the further *chemical* changes which slaked limes undergo when exposed to the air or buried in the soil.

§ 3. *Changes which the hydrates of lime and magnesia undergo by prolonged exposure to the air.*

When the hydrates of lime or magnesia obtained by slaking are exposed to the open air, they gradually absorb carbonic acid from the atmosphere, and tend to return to the state of carbonate in which they existed previous to burning. By mere exposure to the air, however, they do not attain to this state within any assignable time. In some walls 600 years old, the lime has been found to have absorbed only *one-fourth* of the carbonic acid necessary to convert the whole into carbonate; in others, built by the Romans 1800 years ago, the proportion absorbed has not exceeded *three-fourths* of the quantity contained in natural lime-stones. In damp situations the absorption of carbonic acids proceeds most slowly.

1°. *Change undergone by pure lime during spontaneous slaking.*—In consequence, however, of the strong tendency of caustic lime to absorb carbonate acid, a considerable quantity of the hydrate of lime first formed, during spontaneous slaking, becomes changed into carbonate during during the slaking of the rest. But, when it has all completely fallen, the rapidity of the absorption ceases, and the fine slaked lime consists of

Carbonate of lime - - - - - - -			57·4
Hydrate of lime	lime,	32·4	42·6
	water,	10·2	
			100

or, a ton of lime, left in the open air till it has completely fallen to powder, contains about 8½ cwt. in the state of hydrate. If left to slake in large heaps, the lime in the interior of those heaps will not absorb so much carbonic acid till after the lapse of a very considerable time. More caustic lime (hydrate) also will be present if it be left to slake, as is often done for agricultural purposes, in shallow pits covered with sods, to defend it from the air and the rains.

After the lime has attained the state above described, and which is a chemical compound* of carbonate with hydrate of lime, the further absorption of carbonic acid from the air proceeds very slowly, and is only completely effected after a very long period.

2°. *When slaked in the ordinary way* lime falls to powder, without having absorbed any notable quantity of carbonic acid. Numerous small lumps also remain, which, though covered with a coating of hydrate, have not themselves absorbed any water. The absorption of carbonic acid by this slaked lime is at first very rapid,—so that where the full effect of caustic lime upon the soil is required, it ought to be ploughed in as early as possible,—

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* This compound consists of one atom of carbonate of lime ($CaO+CO_2$) combined with one of hydrate ($CaO+HO$), and is represented shortly by $\dot{Ca}\ddot{C}+\dot{Ca}\dot{H}$—in which Ca denotes calcium (Part II. p. 286), Ca O or $\dot{Ca}$ oxide of calcium or lime, CO^2 or $\ddot{C}$ carbonic acid (Part I. p. 61), and HO or $\dot{H}$ water (Part I. p. 43).

but it gradually becomes more slow, a variable proportion of the compound of carbonate and hydrate above described is formed, and even when thinly scattered over a grass field, an entire year may pass over without effecting the complete conversion of the whole into carbonate.

3°. *Calcined or burned magnesia*, whether in the pure state or mixed with quick-lime, as in the magnesian limes, absorbs carbonic acid more slowly—and by mere exposure to the air will probably never return to its original condition of carbonate.

When allowed to slake spontaneously, three fourths of it become ultimately changed into carbonate, and form a compound of hydrate and carbonate which is identical with the common uncalcined magnesia of the shops. This compound* consists of—

Carbonate of Magnesia - -	69·37
Hydrate of Magnesia - - -	16·03
Water - - - - - - - - -	14·60
	100

and it undergoes no further change by continued exposure to the air.

But if slaked by the direct application of water, magnesia, like lime, forms a hydrate only, without absorbing any sensible quantity of carbonic acid. The hydrate thus produced is met with in the form of mineral deposits on various parts of the earth's surface, and this mineral is not known to undergo any change or to absorb carbonic acid though exposed for a great length of time to the air. When magnesian limes are slaked by water, therefore, the magnesia they contain may remain in whole or in part in the caustic state (of hydrate), which will change but slowly even when exposed to the air. When it is left to spontaneous slaking, one-fourth of it at least will always remain in the caustic state, however long it may be exposed to the air.

Should a lime be naturally of such a kind, or be so mixed with the ingredients of the soil as to form a hydraulic cement or an ordinary mortar, which will solidify when rains come upon it, or when the natural moisture of the soil reaches it—the absorption of carbonic acid will in a great measure cease as it becomes solid, and a large proportion of the lime will remain caustic for an indefinite period.

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* It is represented by the formula 3 $(\text{Mg}\ddot{\text{C}} + \dot{\text{H}}) + \text{Mg}\dot{\text{H}}$.

§ 4. *States of chemical combination in which lime may be applied to the land.*

There are, therefore, four distinct states of chemical combination, in which pure lime may be artificially applied to the land.

1°. *Quick-lime or lime shells*, in which the lime as it comes from the kiln is uncombined either with water or with carbonic acid.

2°. *Slaked lime or hydrate of lime*, in which by the direct application of water it has been made to combine with about one-fourth of its weight of water.

In both these states the lime is caustic, and may be properly spoken of as caustic lime.

3°. *Spontaneously slaked lime*, in which one-half of the lime is combined with water and the other half with carbonic acid. In this state it is only half caustic.

4°. *Carbonate of lime*—the state in which it occurs in nature, and to which burned lime, after long exposure to the air, more or less perfectly arrives. In this state lime possesses no caustic or alcaline (Part I. p. 67, note) properties, but is properly called *mild* lime.

5°. Bi-*carbonate of lime* may be adverted to as a fifth state of combination, in which, as I have previously explained to you (Part I. p. 62), nature usually applies lime to the land. In this state it is combined with a double proportion of carbonic acid, and is to a certain extent readily soluble in water. Hence, springs are often impregnated with it, and the waters that gush from fissures in the lime-stone rocks spread it through the soil in their neighbourhood, and sweeten the land.

I shall hereafter speak of these several states under the names of *quick*-lime, hydrate of lime, spontaneously slaked lime, carbonate of lime, and Bi-carbonate of lime. By adhering to these strictly correct names, we shall avoid some of that confusion into which those who have hitherto treated of the use of lime as a manure have unavoidably fallen. The term *mild*, you will understand, applies only to that which is entirely in the state of *carbonate*.

Magnesia, in the magnesian limes, may in like manner be either in the state of *calcined magnesia*, of *hydrate of magnesia*, of *spontaneously slaked*—meaning by this the compound of hydrate with carbonate—of *carbonate*, or of Bi-*carbonate of magnesia*, the latter of which is soluble in water to a very considerable extent.*

§ 5. *Of the various natural forms in which carbonate of lime is applied to the land.*

In the unburned or natural state, lime is met with on the earth's surface in numerous forms—in many of which it can be applied largely, easily, and with economy to the land.

1°. *Marl.*—Of these forms, that of marl occurs most abundantly, and is most extensively used in almost every country of Europe. By the term marl, is understood, as I explained to you when treating of soils (Part II., p. 342), an earthy mixture, which contains carbonate of lime, and effervesces more or less sensibly when an acid (vinegar or diluted muriatic acid—*spirit of salt*) is poured upon it. Generally, also, the tenacious marls, when introduced into water, lose their coherence, and gradually fall to powder. This test is often employed to distinguish between marly and other clays, yet the falling asunder, though it afford a presumption, is not an infallible proof that the substance tried is really a marl.

Marls are of various colors, white, grey, yellow, blue and of various degrees of coherence, some occurring in the form of a more or less fine, loose, sandy powder, others being tenacious and clayey, and others, again, hard and stony. These differences arise in part from the kind and proportion of the earthy matters they contain, and in part, also, from the nature of the locality, moist or dry, in which they are found. The hard and stony varieties are usually laid upon the land, and exposed to the pulverizing influence of a winter's frost before they are either spread over the pasture or ploughed into the arable land. Some rich marls consist in part or in whole of broken and comminuted shells, which clearly indicate the source of the calcareous matter they contain.

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* It dissolves in 48 times its weight of water—or a gallon of water will dissolve 5 ounces of the Bi-carbonate containing 1 3-5 ounces of magnesia.

The characteristic property of true marls of every variety is, I have said, the presence of a considerable per centage of carbonate of lime in the state of a fine powder, and, in general, diffused uniformly through the entire mass. To this calcareous matter the chief efficacy of these marls is no doubt to be ascribed, yet as they always contain other chemical compounds to which the special efficacy of certain varieties has sometimes been ascribed, it may not be improper to direct your attention to the following table in which the constitution of several marls, from different localities, is represented, after the analysis of Sprengel:—

	COMPOSITION OF MARLS FROM					
	Luneburg.	Osnabruck	Magdeburg.	Brunswick.	Weser-marsh.	Brunswick.
	powdery.	*stony.*	*clayey.*	*loamy.*	*powdery.*	*stony.*
Quartz-Sand and Silica	5·6	23·0	58·4	73·4	78·9	71·1
Alumina - - - - - -	0·4	10·0	8·4	1·9	3·1	4·0
Oxides of Iron - - -	4·2	1·9	6·7	3·2	3·8	6·5
Do. of Magnesia -	trace	trace	0·3	0·3	0·3	1·1
Carbonate of lime - -	85·5	35·0	18·2	18·1	8·2	13·3
Do. of Magnesia - -	1·25	0·9	3·8	1·5	3·0	2·6
Sulphuret of Iron - -	—	7·3	—	—	—	—
Potash and Soda, combined with Silica - - - - -	0·05	trace	1·6	0·8	0·9	0·2
Common Salt - - -	0·03	trace	trace	trace	0·1	trace
Gypsum - - - - - -	0·06	0·9	2·1	0·1	0·5	trace
Phosphate of Lime (bone earth)	2·3	0·5	0·5	0·7	1·2	1·2
Nitrate of Lime - - -	0·01	—	—	—	—	—
Organic Matter - -	0·6	carbon 20·5	—	—	—	—
	100	100	100	100	100	100

Several reflections will occur to you on looking at these tables—such as

First—that marls differ very much in composition, and therefore must differ very much also in the effects which they are capable of producing when applied in the same quantity to the same kinds of land.

Second—that, among other differences, the proportion of carbonate of lime is very unlike—in some varieties amounting to 85 lbs. out of every hundred, while in others as little as 5 lbs. are present in the same weight. You will understand, therefore, how very different the quantity applied to the land must be, if these several varieties are to produce an equal liming or to add equal quantities of lime to the soil. You will see that each of three persons may be adopting the best practice with his own marl—though the one add only 12 to 20 tons per acre, while the second adds 50 to 60, and the third 100 to 120 tons.

Third—that the proportion of phosphate of lime (bone-earth) is in some marls considerably greater than in others. Thus with every ton of the first of the above marls you would lay on the soil 52 lbs. of bone earth—about as much as is contained in a cwt. of bone-dust—while with the second you would only add 11 lbs. In so far as their effects upon the land depend, or are influenced by the presence of this substance, therefore, they must also be very different. And

Fourth—that the mechanical effects of these marls upon the soil to which they are added must be very unlike, since some contain 70 or 80 lbs. of sand in every hundred—while others contain a considerable quantity of clay. The opening effects of the one marl, and the stiffening effects of the other, when they are laid on in large quantities, cannot fail to produce very different alterations in the physical characters of the soil.

2°. *Shell Sand.*—The sands that skirt the shores of the sea are found in many localities to be composed, in large proportion, of the fragments of broken and comminuted shells. These form a calcareous sand, mixed occasionally with portions of animal matter, and, when taken fresh from the sea-shore, with some saline matter derived from the sea.

Such is the case in many places on the coast of Cornwall. From these spots the sand is transported to a distance of many miles into the interior for the purpose of being laid upon the land. It has been estimated* that seven millions of cubic feet are at present employed every year in that county for this purpose.

On the western coast of Scotland also, and on the shores of the island of Arran and of the Western Isles, this shell sand abounds, and is applied extensively, and with remarkably beneficial effects, both to the pasture lands and to the peaty soils that cover so large an area in this remote part of Scotland. It is chiefly along the coasts that it has hitherto been extensively employed, and it is transported by sea to a distance of 80 or 100 miles. "In the island of Barray alone, there are four square miles of shells and shell sand of the finest quality and of an indefinite depth."† When covered with a dressing of this shell sand the peaty surface becomes covered with a sward of delicate grass—and the border of green herbage that skirts the shores of these islands in so many places is to be ascribed either to the artificial application of such dressing or to the natural action of the sea winds in strewing the fine sand over them, when seasons of storm occur.

The coast of Ireland is no less rich in such sand in many parts both of its northern and southern coasts. A century and a half ago, it is known to have been used for agricultural purposes in the north of Ireland—and nearly as long ago to have been brought over to the opposite (Galloway) coast of Scotland with a view of being applied to the land (Macdonald). In the south, according to Mrs. Hall,‡ the coral sand raised in Bantry Bay alone produces £4000 or £5000 a-year to the boatmen who procure it and to the peasants who convey it up the country.

On the coasts of France, and especially in Britany, opposite to Cornwall on the other side of the English channel, it is obtained in large qaantity, and is in great demand.§

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* De la Beche's *Geological Report on Cornwall*, &c., p. 480.

† Macdonald's *Agricultural Survey of the Hebrides*, p. 401.

‡ Mrs. Hall's *Ireland*.

§ Payen and Boussingault. *Annales de Chim. et de Phys.*, *third series*, iii. p 92.

It is applied to the clay soils and to marshy grass lands with much advantage, and is carried far inland for this purpose. It is there called *trez*, and is laid on the land at the rate of 10 to 15 tons per acre. On the southern coasts of France, where shell sand is met with, it is known by the name of *tanque* or *tangue*.

The shell sand of Cornwall contains from 40 to 70 per cent. of carbonate of lime, with an equally variable small admixture of animal matter and of sea salt. The rest is chiefly siliceous sand. Other varieties have a similar composition. Two specimens of *tangue* from the south of France, analysed by Vitalis, and one of shell sand from the island of Isla, partially examined by myself, consisted of

	Tangue, from the South of France.		Shell Sand, from Isla.
Sand, chiefly siliceous - -	20·3	40	71·7 to 65·7
Alumina and Oxide of Iron -	4·6	4·6	
Carbonate of Lime - - -	66 0	47 5	28 to 34
Phosphate of Lime - - -	?	?	0·3
Water, and loss - - - -	9·1	7·9	—
	100	100	100

3°. *Coral Sand* is similar in its nature to the shell sand with which it is often intermixed on the sea-shore. It is collected in considerable quantities, however, by the aid of the drag—being torn up by the fishermen in a living state—on the coasts of Ireland (Bantry Bay and elsewhere), and on the shores of Britany, especially near the mouths of the rivers. In this fresh state it is preferred by the farmer, probably because it contains both more saline and more animal matter. This animal matter enables it to unite in some measure the beneficial effects which follow from the application of marl and of a small dressing of farm-yard or other valuable mixed manure.

Payen and Boussingault ascribe the principal efficacy of the shell and coral sands to the small quantity of animal matter which is present in them. These chemists estimate the relative manuring powers of different substances applied to the land by the quantities of nitrogen which they severally contain, and thus, compared with farm-yard manure, attribute to the shell and coral sands the following relative values :—

	Contain of Nitrogen.	Relative values.
100 lbs. of Farm-yard Manure - -	0·40 lbs.	100
- - - of Coral Sand (*Merl*) - -	0·512 lbs.	128
- - - of Shell Sand (*Trez*) - -	0·13 lbs.	32½*

That is to say, that, in so far as the action of these substances is dependent upon the nitrogen they contain, fresh coral sand is nearly one-third *more* valuable than farm-yard manure, while fresh shell sand is only equal in virtue to one-third of its weight of the same substance.

Though, as I have already had frequent occasion to observe to you, much weight is not to be attached to such methods of estimating the relative values of manuring substances by the proportions of any one of the ingredients they happen to contain—yet the fact, that so much animal matter is occasionally present in the living corals, accounts in a satisfactory manner for the *immediate* effects of this form of calcareous application. This animal matter acts directly and during the first year; the carbonate of lime begins to show its beneficial influence most distinctly when two or three years have passed.

4°. *Lime-stone Sand and Gravel.*—In countries which abound in lime-stones, there are found scattered here and there, in the hollows and on the hill sides, banks and heaps of sand and gravel, in which rounded particles of lime-stone abound. These are distinguished by the names of lime-stone sand and gravel, and are derived from the decay or wearing down of the lime-stone and other rocks by the action of water. Such accumulations are frequent in Ireland. They are indeed extensively diffused over the surface of that island, as we might expect in a country abounding so much in rocks of mountain lime-stone. In the neighbourhood of peat bogs these sands and gravels are a real blessing. They are a ready, most useful, and largely employed means of improvement, producing, upon arable land, the ordinary effects of liming, and, when spread upon boggy soils, alone enabling it to grow sweet herbage and to afford a nourishing pasture. The proportion of carbonate of lime these sands and gravels contain is very variable. I have examined two varieties from Kilfinane, in the county of Cork(?). The one, a yellow sand, contained 26 per cent. of carbonate of lime—the residue, being a fine red sand, chiefly siliceous; the other, a fine gravel of a grey colour, contained 40 per cent. of carbonate of lime in the form chiefly of rounded fragments of blue lime-stone, the residue consisting of fragments of sand-stone, of quartz, and of granite.

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* *Annales de Chim. et de Phys., third series*, iii. p. 109.

The application of such mixtures must not only improve the physical characters of the soil, but the presence of the fragments of granite, containing undecomposed felspar and mica (Part II. p. 376), must contribute materially to aid the fertilizing action of the lime-stone with which they are mixed.

5°. *Crushed Lime-stone.*—The good effects of calcareous marls and of lime-stone gravels naturally suggest the crushing of lime-stones as a means of obtaining carbonate of lime in so minute a state of division that it may be usefully applied to the soil. Lord Kames was, I believe, the first who in this country endeavoured to bring this suggestion into practical operation. He is said to have caused machinery to be erected for the purpose in one of the remotest districts of Scotland, but from some cause the plan seems never to have obtained a proper trial.

One of the results which, as we have already seen, follows from the burning of rich lime is this, that it naturally falls to a very fine powder as it slakes. Where coal or other combustible is cheap, therefore, it may possibly be reduced to a fine powder by burning, at a less cost than it could be crushed.

Yet there are two cases or conditions in which crushing might be resorted to with equal advantage and economy.

First, where coal is dear or remote, while lime-stones and water power are abundant. There are many inland districts in each of the three kingdoms where these conditions exist, and in which, therefore, the erection of cheap machinery might afford the means of greatly fertilizing the land; and

Second.—There are in many localities rocks rich in calcareous matter, which are nevertheless so impure, or contain so much other earthy matter, that they cannot be burned into lime. Yet, if crushed, these same masses of rock would form a valuable dressing for the land. Many lime-stones of this impure character, which are really useless for building purposes—which do not fall to powder when burned, and which have, therefore, been hitherto neglected as useless—might, by crushing, be made extensively available for agricultural purposes. The siliceous lime-stones (corn-stones) of the old red sand-stone, the earthy beds of the mountain lime-stone, and many of the calcareous strata of the silurian system might thus be made to improve more extensively the localities in which they are severally met with. The richer limes now brought from a great distance, and at much expense—as on the Scottish borders—might be in a great measure superseded by the native produce of the district.

§ 6. *Effects of marl and of the coral, shell, and lime-stone sands upon the soil.*

The effects which result from the application of the above natural forms of carbonate of lime are of two kinds.

1°. Their *physical* effect in altering the natural texture of the soils to which they are added. This effect will necessarily vary with the nature of the earthy matter associated with the lime. Thus the clay marls will improve, by stiffening, such soils as are light and sandy—the shell sands and lime-stone gravels, by opening and rendering more free and easier worked such soils as are stiff, intractable, and more or less impervious—while either will impart solidity and substance to such as are of a peaty nature or over-abound with other forms of vegetable matter.

2°. Their *chemical* effect in actually rendering the soil productive of larger crops. This effect is altogether independent of any alteration in the physical properties of the soil, and is nearly the same in *kind*, whatever be the variety of marl, &c., we apply. It differs in *degree*, chiefly according to the proportion of calcareous matter which each variety contains. This action of the pure carbonate of lime they contain is supposed to be modified in some cases by the proportion of phosphate of lime, &c. (Part III. p. 104) with which it may be mixed—it is certainly modified by the animal and saline matters which are present in the recent corals and shell sands.

The several effects of marl and calcareous sands being dependent upon circumstances so different, it is not surprising that the opinions of practical men should, in former times, have been divided in regard to the action of this or that marl upon their respective soils. In no two localities was the substance applied to the land exactly alike, and hence unlike results must necessarily have followed, and disappointment been occasionally experienced from their use. And yet the importance of rightly understanding the kind and degree of effect which these manuring substances ought to produce may be estimated from the fact, that a larger surface of the cropped land in Europe is improved by the assistance of calcareous marls and sands—than by the aid of burned lime and of farm-yard manure put together.

It is not easy in any case to estimate with precision what portion of the effect caused by a given marl is due to its chemical and what to its physical action. Even the pure limes, when applied in large doses, produce a change in the texture of the soil, which on stiff lands is beneficial, and on light or sandy fields often injurious. In all cases, therefore, the action of lime applied in any form may be considered as partly physical and partly chemical—the extent of the chemical action in general increasing with the proportion of lime which the kind of calcareous matter employed is known to contain.

The *observed* effects of marls and shell sands, in so far as they are chemical, are very analogous to those produced by lime as it is generally applied in the quick or slaked state in so many parts of our islands.

They alter the nature and quality of the grasses when applied to pasture—they cover even the undrained bog with a short rich grass—they extirpate heath, and bent, and useless moss—they exterminate the weeds which infest the unlimed corn fields—they increase the quantity and enable the land to grow a better quality of corn—they manifest a continued action for many years after they have been applied—like the purer limes they act more energetically if aided by the occasional addition of other manure—and like them they finally exhaust* a soil from which successive crops are reaped, without the requisite return of decaying animal or vegetable matter.

But to these and other effects I shall have occasion to draw your attention more particularly in a subsequent part of the present lecture.

§ 7. *Of the use of chalk as a manure.*

Chalk is another form of carbonate of lime which occurs very abundantly in nature, and which, from its softness, has in many parts of England been extensively applied to the land in an unburned state.

The practice of chalking prevails more or less extensively in all that part of England (Part II., p. 357) over which the chalk formation extends. It is usually dug up from pits towards the close of the autumn or the beginning of winter, when full of water, and laid upon the land in heaps. During the winter's frost the lumps of chalk fall to pieces and are readily spread over the fields in spring. The quantity laid on varies with the quality of the soil and of the chalk itself, and with the more or less perfect crumbling it undergoes during the season of winter, and with the purpose it is intended to serve. It gives tenacity and closeness to gravelly soils,† opens and imparts freeness to stiff clays, and adds firmness to such as are of a sandy nature.

If a physical improvement of this kind be required, it is laid on at the rate of from 400 to 1000 bushels an acre But some chalks contain much more clay than others, and are employed, therefore, in smaller proportions.

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* Of shell marl the same quantity exhausts sooner than clay marl (Kames). This is owing chiefly to the larger proportion of lime contained in the former.

† Mr. Gawler, North Hampshire, states that a gravel thus stiffened, instead of 12 to 16 bushels of wheat, yielded afterwards 24 to 30 bushels.—*British Husbandry*, i., p. 280.

For the improvement of coarse, sour, marshy pasture, it is applied at the rate of 150 to 250 bushels an acre, and speedily brings up a sweet and delicate herbage. It is also said to root out sorrel from lands that are infested with this plant.

These effects are precisely such as usually follow from the application of marl, and, like marl, the repetition of chalk exhausts the land, if manure be not afterwards added to it in sufficient quantity.

But the chalking of the Southern Downs and of the Wolds of Lincolnshire and Yorkshire would appear to differ in some respects from ordinary marling. On the thin soils immediately resting upon the chalk, experience has shown that repeated dressings of chalk, recently dug up, may be applied with much benefit. To a stranger, also it appears singular that an admixture of that chalk which lies immediately beneath the soil is not productive of the same advantage. Even the chalk of an entire district is, in some cases, rejected by the farmer, and he will rather bring another variety from a considerable distance, than incur the less expense of laying on his land that which is met with on his own or on his neighbour's farms. Thus the Suffolk farmers prefer the chalk of Kent to lay on their lands, and are at the cost of bringing it across the estuary of the Thames, though chalk rocks lie almost every where around and beneath them.

The cause of the diversities which thus present themselves in the practice of experienced agriculturists is, partly at least, to be sought for in the qualities of the different varieties of chalk employed. Careful analyses have not yet shown in what respects these chalks differ in chemical constitution, and until this is ascertained we must remain in some measure in the dark, both as to the way in which a dressing of chalk acts in improving a soil already rich in chalk, and why chalk from one locality should act so much more beneficially than another.

With one thing, however, we are familiar, that the upper beds of chalk abound in flint, and where they form the surface support a thin and scanty herbage—while the under chalks are more tenacious and apparently more rich in clay, and support generally a soil which yields valuable crops of corn. An admixture of the lower, therefore, ought to improve the soils of the upper; and as the chalks of Kent consist of these lower beds, we can understand why the practical farmer in Suffolk should prefer them to the upper chalks of his own neighbourhood. Still we cannot, as yet, give the scientific reason why the one chalk should be better than the other. A rigorous chemical analysis can alone determine with certainty why the one should produce a different effect from the other.

Chalks *may* differ in the proportion of clay or of organic matter with which they are associated—in the quantity of silica (the substance of flints) or of silicates they contain,—in the amount of magnesia or of phosphate of lime which can be detected in them—or of saline matter which a careful examination will discover,—and they may even differ physically in the fineness of the ultimate particles of which the substance of the chalk is composed.* All such differences may modify the action of the several varieties in such a way as, when accurately investigated, to enable us to account for the remarkable preference manifested by practical men for the one over the other. Until such an investigation has been carefully made, it is unfair hastily to class among local prejudices what may prove to be the results of long practical experience.

On the chalk Wolds of Lincolnshire and Yorkshire the practice of chalking even the thin soils is now comparatively old in date. The lowest chalks are there also much preferred,—they are laid on at the rate of 60 to 80 cubic yards per acre, and they cause a great improvement, especially upon the *deep lands*, as they are called, where the soil is deepest. Corn does not yield so well, nor ripen so early, on these deep soils as where a thinner covering rests upon the chalk. It is naturally also unfit for barley or turnips, the latter plant being especially infested with the disease called fingers and toes* (Strickland). But a heavy chalking removes all the above defects of these deep soils, and for a long period of time. The corn ripens sooner, is larger in quantity, and better in quality, and the turnips grow perfectly free from disease.

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* Ehrenberg has discovered that chalk is in a great measure composed of the skeletons, shells, or other exuvial (spoils) of marine microscopic animals.

These, however, are to be regarded as only the usual effects of a large addition of lime to a soil in which previously little existed. It is a fact which will naturally strike you as remarkable, that soils which rest upon chalk, as well as upon other lime-stone rocks, even at the depth of a few inches only, are often, and especially when in a state of nature, so destitute of lime that not a particle can be detected in them. That lime in any form should benefit such soils is consistent with uniform experience. I shall presently have an opportunity of directing your attention to the *two* concurring causes by the joint operation of which lime is sooner or later wholly removed from the soil, even where, as in the Wolds, it rests immediately upon the chalk.

§ 8. *Is lime indispensable to the fertility of the soil?*

It is the result of universal experience wherever agriculture has been advanced to the state of an art, that the presence of lime is useful to the soil. Not only is this fact deduced from the result of innumerable applications of this substance to lands of every quality, but it is established also by a consideration of the known chemical constitution of soils which are naturally possessed of unlike degrees of fertility.

Thus sandy or siliceous soils are more or less barren if lime be absent—while the addition of this substance in the form of marl or otherwise renders them susceptible of cultivation. So clay soils, in which no lime can be detected, are often at once changed in character by a sufficient liming. Felspar soils contain no lime, and they are barren—and the same is true of such as are derived immediately from the degradation of the serpentine rocks.

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* *British Husbandry*, iii., p. 124.

Trap soils, on the other hand—such as are derived from decayed basalts or green-stones—are poor in proportion as felspar abounds in them. Where augites and zeolites are present in large proportion in the trap from which they are formed, the soils are rich, and may even be used as marl. The only difference in this latter case is, that lime is not deficient (Part II. p. 388),—and to this difference the greater fertility may fairly be ascribed.

But let it be conceded that lime is useful to or benefits the soil in which it exists, you may still ask—is lime *indispensable* to the soil?—is it impossible for even an average fertility to be manifested where lime is entirely absent?

There are two different considerations, from each of which we may deduce a more or less satisfactory answer to this question.

1°. The results of all the analyses hitherto made of soils naturally fertile show that lime is universally present. The per-centage of lime in a soil may be very small, yet it can always be detected when valuable and healthy crops will grow upon it. Thus the fertile soil of the

	Per cent.	
Marsh lands in Holstein contains	0·2	of carbonate of lime.
Salt Marsh in East Friesland	0·6	- - - -
Rich pasture near Durham	1·31	- - - -

But though the per-centage of lime in these cases appears small, the absolute quantity of lime present in the land is still large. Thus suppose the first of these soils, which contains the least, to be only six inches in depth, and each cubic foot to weigh only 80 lbs.—it would contain about 3500 lbs. of carbonate of lime, upwards of a ton and a half, in every acre. And this lime would be intimately mixed with the whole soil, in which state it is always most effective in its operation. It may also be inferred with safety, that if the upper six inches contained this proportion of lime, the under soil would probably be richer still, since lime tends not so much to diffuse itself through, as to sink downwards into the soil.

2°. The results of all the chemical examinations hitherto made in regard to the nature of the inorganic matter contained in the sap and substance of plants indicate,—if not the absolute necessity of lime to the growth of plants,—at least that in nature all cultivated plants do absorb it by their roots from the soil, and make use of it in some way in aid of their growth. In so far as our practice is concerned, this is very much the same as if we could prove lime to be absolutely indispensable.

The ash of the leaf and bulb of the turnip or potato, of the grain and straw of our corn-bearing plants, and of the stems and seeds of our grasses, all contain lime whenever and wherever they are grown. And most of them attain high health and luxuriance only where lime is easily attained.

Grant, then, that lime *appears* to be, perhaps virtually is, a necessary food of plants, without which their natural health cannot be maintained, nor functions discharged,—still the quantity which must be present in the soil to supply this food is not necessarily large. Even in favourable circumstances we have seen (Part II. 326) that the average crops during an entire rotation of four years may not carry off more than 250 lbs. of lime from the acre of land, a quantity which even the marsh soils of Holstein would be able to supply for half a century, could the roots readily make their way into every part of the soil.

Still we may safely hold, I think, that this quantity of lime at least is *indispensable*—if cultivated plants are to flourish and ripen. So much, *at least*, must in practice be every year added to cultivated land in one form or another, where the crops are in whole or in part carried off the land. Where it is not added either artificially or by some natural process, infertility must gradually ensue. We shall presently see that lime has other functions to perform in the soil, and that there are natural causes in constant operation in our climate which render a larger addition than this desirable at least, if not indispensable to continued fertility.

§ 9. *State of combination in which lime exists in the soil.*

This lime, which we have concluded to be an indispensable constituent of fertile soils, may be present in several distinct states of combination.

1°. *In that of chloride of calcium.*—This compound, as we have already seen (Part II. p. 286), is very soluble in water, and is not unfrequently to be detected in the sap, especially of the roots of plants. Its solubility, however, exposes it to be readily washed out of the soil by the rains, and perhaps for this reason it is not one of those forms of combination in which lime is recognised as a uniform or necessary constituent of the soil. Its presence may be detected by boiling half a pound of the soil in distilled water, filtering and evaporating the solution to dryness. If the dry mass become moist on exposure to the air, and if, after being dissolved in water, it give a white precipitate with oxalate of ammonia, and after being rendered sour by a few drops of nitric acid, a white precipitate again with nitrate of silver, it may be inferred to contain chloride of calcium.

2°. *In that of sulphate of lime or gypsum.*—In this state also it is not a constant, and in a few cases only an abundant, constituent of the soil. Its presence may be detected by the deposition of minute crystals on the sides of the vessel during the evaporation of the solution obtained by boiling the soil in distilled water. Or, its presence may be inferred if, after observing that oxalate of ammonia causes a precipitate in one small portion of the solution, it be found that nitrate of baryta also throws down a white precipitate from another small portion.

3°. *In the state of phosphate*—This compound is probably present, though always in small proportion, in every soil which is capable of raising a nutritious vegetation. It may be readily detected by treating 500 grains of the dry soil for 12 hours with dilute muriatic acid, and occasionally stirring. If to the filtered solution caustic ammonia be added, a brownish precipitate will usually fall. If this precipitate be separated, and treated with acetic acid (vinegar), it will all dissolve if no phosphoric acid be present. If this experiment be carefully performed, and a residue remain undissolved, the presence of phosphoric acid in the solution, and of phosphate of lime in the soil, may be safely inferred.

4°. *In the state of silicate*, lime rarely exists in the soil in any considerable quantity. It is chiefly in such as are derived from the decay of the trap rocks or of some varieties of granite (Sienite), that silicate of lime is to be expected to occur.

If, after being treated with dilute sulphuric acid, as above described, the soil be digested for some hours at a gentle heat with concentrated muriatic acid—a solution will be obtained from which ammonia will again throw down a brown precipitate. If oxalate of ammonia now cause a white precipitate of oxalate of lime, and if, on evaporating to dryness, the solution leave a portion of silica insoluble in acids, we may infer that the soil most probably contains some lime in the state of silicate.

5°. *In the state of carbonate*, lime is generally supposed most usually to exist, and most abundantly in all soils. If on pouring dilute muriatic acid upon a soil, a visible effervescence or escape of minute bubbles of gas manifest itself, or if, when the experiment is made in a tube closed at one end, and inverted over water or mercury, bubbles of gas collect in the upper end of the tube—the soil contains *some* carbonate. If after ammonia has been added to the solution, oxalate of ammonia throws down a white precipitate of oxalate of lime—the soil contains carbonate of *lime*.

6°. *In the state of humate.*—In combination with humic acid (Part II. p. 406) lime exists most frequently in soils which abound in vegetable matter—in peaty soils, for example, to which quick-lime or marl of any kind have been added for the purpose of agricultural improvement. The presence of lime in the state of humate is only to be detected by carefully determining the relative weights of the carbonic acid given off during the action of dilute muriatic acid upon the soil, and of the lime contained in the solution thus obtained.* If for every 100 grains of carbonic acid there be more than 77·24 grains of lime, the remainder or excess has existed in the soil in combination with humic or some analogous organic acid.†

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* See Appendix, No. V.

† To such analogous acids belong the *crenic* and *apocrenic* acids (Part II.

Few investigations have as yet been made in regard to the proportion of lime which exists in the soil in the state of humate. It has generally been taken for granted—either that a soil was destitute of lime if it exhibited no sensible effervescence with dilute muriatic acid,—or when further research was made, and the quantity of lime taken up by this acid rigorously determined, that the whole of this lime must have existed in the soil in the state of carbonate. That this is not necessarily the case, however, appears to be proved by some recent examinations of certain soils in Normandy, which contain as much as 14 to 15 per cent. of lime, and yet exhibit no effervescence, and contain no carbonate. The whole of the lime is said to be in the state of humate.

M. Dubuc, who has published the analyses of these soils, attributes much of their fertility to the presence of the *humate* of lime. Thus he says that the soils of

	Containing per cent.		
	Of Carbonate.	Of Humate.	Yields of Wheat.
Lieuvin, Neubourg, and Sistot - -	0	18 to 20	12 to 15 fold.
Pavilli - - -	0	5	8 to 10 ...
Bieville - - -	24	0	8 to 10 ...
Clay of Ouche -	0	1	4 to 5 ...

the first two yielding a wheat crop every second year, the third only at longer intervals.

Whatever degree of influence on the fertility of the soil it may appear proper to attribute to the existence of lime in the soil in the state of humate, it is manifestly of some importance that its presence in this state of combination should be more frequently and more carefully sought after.

The only one of the above compounds which is *usually* added to the land, for the purpose of producing the ordinary effects of lime, is the carbonate. Gypsum is applied only in small quantity for certain special purposes, and does not always produce a sensible effect. It is incapable, therefore, of performing those purposes in the soil which

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p. 408). The existence of these acids in the soil is by no means problematical. According to Professor Hermann, of Moscow, they exist in the rich black soil (Tchornoi Zem.) of Little Russia, to the amount of 4 per cent.

are served either by quick-lime or by the carbonate. The humate of lime is probably formed in our *lime composts*, especially when much vegetable matter is contained in them, and may thus be not unfrequently applied directly to the land.

§ 10. *Of the quantity of lime which ought to be added to the soil.*

The quantity of lime which ought to be added to the soil is dependant upon so many circumstances, that it is impossible to state any general rule by which, in all cases, the practical man can safely regulate his procedure.

1°. To soils which contain no lime, or to which it is added for the first time, a larger dose must be given.

We have seen that a certain *minimum* portion of lime is indispensable to a productive soil. If we suppose this smallest quantity to be no greater than in the surface of the marsh lands of Holstein (Part III. p. 116),—then with a soil six inches in depth—which *contains no lime*, we ought to mix a ton and a half, say 40 bushels of slaked lime, and by successive yearly additions to supply the annual waste.

But to mix this feeble dose of lime intimately with the soil to a depth of six inches would obviously require an expenditure of labour which the practical farmer could rarely afford. It would be greater economy, therefore, in most cases to add a dose several times larger, and this not only because the same amount of labour would diffuse it more generally through the whole soil, but because this larger liming would render less necessary the immediate addition of new supplies to repair the unavoidable waste.

But there is reason to believe that the proportion of lime which the soil ought to contain, if it is to be successfully subjected to arable culture, ought to be much larger than is above assumed as the smallest or minimum quantity. If we suppose one per cent. to be necessary, then eight tons of lime-shells, or upwards of 300 bushels of slaked lime, must be mixed with a soil six inches in depth, to impart to it this proportion—or half the quantity if it be kept within three inches of the surface. Even a very large dose of lime, therefore, does not, if it be well mixed, materially alter the constitution of the soil.

2°. But experience has proved that the quantity of lime which a skilful farmer will add to his land will vary with many other circumstances besides the depth of his soil, and the proportion of lime it already contains. Thus—

a. On clay lands more lime is necessary than on light and sandy soils. This may be partly ascribed to the physical effect of the lime in opening and loosening the stiff clay—but independent of this action the particles of lime are liable to be coated over and enveloped by the fine clay, and thus shut out from the access of the air. These particles, therefore, must be more numerous in such a soil if as many of them are to be exposed to the air as in lighter land, through which the atmospheric air continually permeates.

b. On wet and marshy soils, a larger application still may be made with safety, and partly for the same reason. The moisture surrounding the lime shuts out the air, without the ready access of which lime cannot perform its important functions. The same moisture tends to carry down the lime and lodge it more speedily in the subsoil. The continued evaporation also keeps such soils too cold (Part I. p. 55), to allow the chemical changes, which lime in favourable circumstances produces, to proceed with the requisite degree of rapidity. The soluble compounds which are formed as the consequence of these changes are, in wet and marshy soils, dissolved by the moisture, and so diluted as to enter in smaller quantity into the roots of plants. And lastly, in certain cases, new compounds of the lime with the earthy and stony matters of the soil are formed, which may either harden into visible lumps of mortar and cement, or into smaller particles of indurated matter, in which the lime is no longer in such a state as to be able to act in an equal degree as an improver of the soil.

In cold and wet clays, in which all these evil conditions occasionally meet, it is not surprising, therefore, that large doses of lime should sometimes have been added without producing any sensible benefit whatever.*

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* "An instance is mentioned in the Nottinghhm Report of 720 bushels

c. Again, when the soil is also rich in vegetable matter, lime may be still more abundantly applied. Thus, when a field is at once wet or marshy, and full of vegetable matter, as our peat bogs are, lime may be laid on more unsparingly than under any other circumstances. For in this case, besides the action of the excess of water, as above explained, the vegetable matter combines with and masks the ordinary action of a considerable quantity of the lime. By this combination, no part of the ultimate influence of the whole lime upon the soil is necessarily lost; in most cases the *immediate* effect only is lessened, which the same quantity applied to other soils would have been seen to produce. In favourable circumstances its action is retarded and prolonged, the compounds it forms with the vegetable matter decomposing slowly, and, therefore, remaining long in the soil.

To the exact chemical constitution of the compounds thus formed, *as soon as* lime is mixed up with a soil rich in vegetable matter, and to the chemical changes which these compounds gradually undergo, it will be necessary to direct our attention when we come to study the *theory* of the action of lime, as an improver of the soil.

d. Not only the natural depth of the soil, as already stated, but also the depth to which it is usually ploughed, and to which it is customary to bury the lime, will materially affect the quantity which can be safely applied. A dose of lime which would materially injure a soil into which the plough rarely descends beyond two or three inches, might be too small an application where six or eight inches are usually turned over by the plough. When new soil, also, is to be brought up, which may be supposed to contain no lime, or in which noxious substances are present, a heavier dose of lime must necessarily be laid upon the land.

3°. Such are the circumstances in which large applications of lime may be usefully applied to the land. In soils of an opposite character not only will smaller quantities

having been laid on an acre of cold clay land without any benefit whatever."—*British Husbandry*, i., p. 296.

of lime produce an equally beneficial effect, but serious injury would often be inflicted by spreading it too lavishly upon your fields.

The more dry and shallow the soil, the more light and sandy, the less abundant in vegetable matter, the more naturally mild its locality, and the drier and warmer the climate in which it is situated—the less the quantity of lime which the prudent farmer will venture to mix with it. It is to the neglect of these natural indications that the exhaustion and barrenness that have occasionally followed the application of lime are to be ascribed. It is only in rare cases, such as the presence of much noxious mineral matter in the soil, that these indications can be safely neglected.

§ 11. *Ought Lime to be applied in large doses at distant intervals, or in smaller quantities more frequently repeated.*

The quantity of lime which ought to be applied to the land must, as we have seen, vary with its quality, and with the conditions in which it is placed. Hence the practice in this respect necessarily varies in every country and in almost every district.

But a difference of opinion also prevails amongst practical men, as to whether that quantity of lime which land of a given kind may require ought to be applied in large doses at long intervals, or in small quantities frequently repeated. The indications of theory in reference to this point are clear and simple.

A certain proportion of lime is indispensable in our climate to the production of the greatest possible fertility. Let us suppose a soil to be wholly destitute of lime—the first step of the improver would be to add to it this indispensable proportion. This would necessarily be a large quantity, and, therefore, *to land limed for the first time theory indicates the propriety of adding a large dose.*

Every year, however, a certain variable proportion of the lime is removed from the soil by natural causes. The effect of this removal in a few years becomes sensibly apparent in the diminished productiveness of the land. After the lapse of five or six years, during which it has been gradually mixing with the soil, the beneficial effects of the lime are generally the most striking—after this they gradually lessen, till at the end of a longer or shorter period, the land reverts to its original condition. *To keep land in its best possible state, therefore, the natural waste ought from time to time to be supplied by the addition of smaller doses of lime at shorter intervals.*

Such is obviously the most natural course of procedure, and he who farms his own estate, and has therefore no strong inducement to do otherwise, will, on the first breaking up of new land give it a heavy liming, and whether he afterwards retain it in arable culture or lay it down to grass, will at intervals of 4 to 6 years give it a new dose of one-fourth to one-eighth of the original quantity. But local circumstances and customs interfere in many well farmed districts with this most natural treatment of the soil. In the county of Roxburgh, for example, on entering upon his farm, which he holds on a lease of 19 or 21 years, the tenant begins by liming that portion of his land which is in fallow, or in preparation for turnips, at the rate of 240 to 300 bushels of quick-lime per acre. A similar liming is given to the other portions as they come into fallow, so that at the end of his first rotation (4 or 5 years) the whole of his land has been limed at the same rate. He now continues cropping for three or four rotations (14 to 16 years), when if he is sure of remaining on his farm he begins to lime again with the same quantity as before. If he is to quit, however, he takes the best crops he can get, but incurs no further outlay in the addition of lime. His successor follows the same course—begins by expending perhaps £1000 in lime, and before he leaves at the end of his lease, has, by continued cropping, brought back his land nearly to the same state in which he found it.

In the district of Kyle and other parts of Ayreshire, again, lime is laid on—often when preparing for the wheat crop, either by ploughing in the seed furrow, or by harrowing in with the seed—at the rate of 40 bushels of shells an acre, and this dose is of course repeated every 4 or 6 years, according to the length of the rotation. If we consider the probable difference in the soil and climate, the proportion of lime added in the two districts does not materially differ. In Ayrshire from 8 to 10 bushels, and in Roxburgh from 10 to 12 bushels are added for each year.* In both counties, however, many farms may be met with in which the treatment of the land in this respect differs from that which is generally followed.

In Flanders a similar difference in the practice prevails in different districts. In some the land is limed only once in 12 years, in others every third, fourth, or sixth year, according to the length of the rotation. In the former case from 40 to 50 bushels are applied per acre, in the latter from 10 to 12 bushels every third year. In both modes of procedure the quantity of lime applied by the year, is nearly the same—between 3½ and 4 bushels per acre. These quantities are very much less than those employed in our island, but the soils are also greatly lighter, and the climate, as well as the general treatment of the land, very different.

We may consider it, therefore, as a principle recognized or involved in the agricultural practice both of our own and of foreign countries, that nearly the same *annual* addition of lime ought to be made to the land, whether it be applied at long intervals or at the recurrence of each rotation. There is, therefore, on the whole, no saving in the cost of lime, whichever method you adopt. A slight consideration of the subject, however, may satisfy us that there is a real difference in the comparative economy or profit of the two methods.

Let us suppose two acres of the same clay land to be limed respectively with 200 bushels each, and that the one is cropped for 20 years afterwards without further liming, while the other at the end of every 5 years is dressed with an additional dose of 40 to 50 bushels. In both cases the land would have attained its most productive condition in five or six years. Let us suppose that in this condition it produced annually a crop of (or equivalent in nutritive value to) 30 bushels of wheat, and that on neither acre did a sensible diminution appear before the end of ten years. Then during the second ten the crops would gradually lessen in the one acre, while, in consequence of the *re*-addition of the lime as it disappears, the amount of produce would remain sensibly the same in the other acre. Suppose the produce of the former gradually to diminish from 30 to 20 bushels during these ten years,—or that while the one has continued to yield 30 bushels during the whole period, the other has, on an average, yielded only 25 bushels during the latter ten years. If now the second large dose of 200 bushels be added to this latter acre, the cost of liming both will have become sensibly the same, but the amount of produce or of profit from the two acres during the second ten years will stand thus—

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* According to General Beatson (*New System of Cultivation*, 1820), upwards of 100 bushels an acre, at a cost of £7 16s., used to be applied to the clay lands of Sussex—on the fallow, before wheat—every four years. This was 25 bushels per acre for each year. In such lands as these the saving in the article of lime alone, which would follow a judicious drainage, would be very great.

10 crops, of 30 bushels each, amount to 300 bushels.
10 crops, of 25 bushels each, amount to 250 bushels.
Difference in favour of frequent liming . . . . 50 bush. p. acre,

or nearly two whole crops every lease of twenty years.

Thus it appears

1°. That, according to the practice of different countries, the quantity of lime which ought to be added, and consequently the cost of adding it, is very nearly the same, whether it be applied in larger doses at longer intervals, or in smaller doses more frequently repeated.

2°. That, *after the first heavy liming*, the frequent application of small doses is the more natural method—and

3°. That it is also the most economical or profitable method.

It is possible that other considerations, such as the tenure by which your land is held may appear sufficient to induce you to depart from this method; but there seems every reason to believe that it will best reward those who feel themselves at liberty to follow the indications at once of sound theory and of enlightened practice.

One thing, however, must be borne in mind by those who, in adopting the best system of liming, do not wish both to injure their land and to meet with ultimate disappointment. Organic matter—in the form of farm-yard manure, of bone or rape dust, of green crops ploughed in, or of peat, and other composts—must be abundantly and systematically added, if at the end of 20 or 40 years the land in which the full supply of lime is kept up is to retain its original fertility. High farming is the most profitable—for the soil is ever grateful for skilful treatment—but he who farms high in the sense of keeping up the supply of lime, must also farm high in the sense of keeping up the supply of organic and other manures in the soil—otherwise present fertility and gain will be followed by future barrenness and loss. If this is not to be done, it were better to add lime at long intervals, since as the quantity of lime diminishes, the land begins to enjoy a little respite, and has had time in some measure to recover itself—the cropping in both instances being the same—before the new dose is laid upon its surface.*

§ 12. *Form and state of combination in which lime ought to be applied to the land.*

The form and state of combination in which lime ought to be applied to the land depend upon the nature of the soil, on the kind of cropping to which it is subjected, and on the special purpose which the lime is intended to effect. The soil may be heavy or light, in arable culture or laid down to grass, and each of these conditions indicates a different mode of procedure in the application of lime. So the lime itself may be intended either to act more immediately or to be more permanent in its action—or it may be applied for the purpose of destroying unwholesome herbage, of quickening inert vegetable matter, of gene-

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* "In the neighborhood of Taunton, in Somersetshire, and over all the soil of the new red sand-stone, the farmers lime their land every time it comes in course of fallow for turnips, and this produces excellent crops, even without dung."—*Morton on Soils*, third edition, p. 181. The practical reader must not consider this custom of the Somersetshire farmers as at all at variance with what is stated in the text; he must conclude, rather,—if the sentence here quoted is meant to imply that they lime their arable land so repeatedly, and yet add no organic manure—that they will, sooner or later, cease to boast of its fertility.

-rally sweetening the soil, or simply of adding to the land a substance which is indispensable to its fertility. The skilful agriculturist will modify the form and mode of application according as it is intended to serve one or other of these purposes.

From the considerations already presented to you (§ 3) in regard to the changes which quick-lime undergoes in the air, it appears to be expedient

1°. To slake lime quickly and to apply it immediately upon clay, boggy, marshy, or peaty lands—upon such also as contain much inert or generally which abound in other forms of vegetable matter.

2°. To bents and heaths which it is desirable to extirpate, it should be applied in the same caustic state, or to unwholesome subsoils which contain much iron (sulphate of iron), as soon as they are turned up by the plough. In both these cases the unslaked lime-dust from the kilns might be laid on with advantage.

3°. Where it is to be spread over grass lands without destroying the herbage, it is in most cases safer to allow the lime to slake spontaneously, and in the open air rather than in a covered pit. It is thus obtained in an exceedingly fine powder, which can be easily spread, and, while it is sufficiently mild to leave the tender grasses unharmed, it contains a sufficient quantity of caustic lime (Part III. p. 100) to produce those chemical changes in the soil on which the efficacy of quick-lime depends.

4°. Where lime is applied to the fallow, is ploughed in, well harrowed or otherwise mixed with the soil, it is generally of little consequence in which of the above states it is laid on. The chief condition is, that it be in the state of a fine powder, and that it be well spread and intimately mixed with the soil. Before these operations are concluded the lime will be very nearly in the state of combination in which it exists in spontaneously slaked lime—whatever may have been the state of causticity in which it has been applied.

You will understand that the above remarks apply only to localities where burned lime is usually or alone used for agricultural purposes. There may be localities where marl also exists, or shell or lime-stone sand, in greater or less abundance, and in such places it may be a question of some importance to determine which it would be better or more economical to apply. In such a case you may safely proceed upon the principle that the lime in the marls, &c., will ultimately produce precisely the same effects upon your land as the lime from the kiln, provided you lay on an equal quantity, and in an equally minute state of division. The effect will only be a little more slow, and the full fertility of the land a year or two longer in being brought out. You would therefore consider

1°. How much of the marl or sand must I add to be equal to a ton of lime-shells? This will depend on the per-centage of lime which the marl contains. Suppose it to contain 20 per cent., or one-fifth of its weight of lime,* then five tons of the marl will be equal to one ton of lime *shells*. But as the lime in the marls and sands is never in so minute a state of division as in the slaked lime, the same quantity of lime in the former cannot be so equally diffused through the soil as in the latter state. An allowance must therefore be made on this account, and an additional quantity equal to one-fourth or one-fifth of the whole added, for the purpose of equalizing the effect.

2°. Which of the two, the quick-lime or its equivalent of marl, can I obtain and apply at the less cost? This will not be difficult to calculate, the proportion of lime contained in the marl being once ascertained.

3°. This question of economy being decided, it is necessary to consider the kind and quantity of the earthy matter with which the lime in the marl is mixed. If it be a lime-sand or sandy marl, it may be unfit to apply to light and sandy soils; if it be a stiff unctuous clay marl, it may only render stiffer and more difficult to work the clay lands on which you may propose to spread it. In such cases as these, however economical the use of marls or lime-stone sands may be, the intelligent farmer will prefer the addition of quick-lime wherever it is readily accessible.

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* Not *carbonate* of lime, but of lime in the state in which it comes from the kiln. 100 lbs. of carbonate contain 56 lbs. of *quick* lime, Part III. p. 96.

Sussex is one of those districts in which the ancient use of marl has given place to the employment of burned lime (Beatson), chiefly, I believe, from the nature of the local marl being less adapted to the stiff clay lands of that county.

§ 13. *Of the use and advantage of the compost form.*

As there are many cases in which lime ought to be applied unmixed and in the caustic state, so there are others in which it is best and most beneficially laid upon the land in a mild state and in the form of compost.

1°. When lime is required only in small quantities, it can be more evenly spread when previously well mixed with from 3 to 8 times its bulk of soil.

2°. On light, sandy, and gravelly soils, when of a dry character, unmixed lime will bring up much cow-wheat (*melampyrum*) and red poppy. If they are moist soils, or if rainy weather ensue, the lime is apt to run into mortar, and thus to form either an impervious subsoil, or lumps of a hard conglomerate, which are brought up by the plough, but do not readily yield their lime to the soil. These bad consequences are all avoided by adding the lime in the form of compost.

3°. Applied to grass lands—unless the soil be stiff clay—or much coarse grass is to be extirpated,—it is generally better and safer to apply it in the compost form. The action of the lime on the tender herbage is by this means moderated, and its exhausting effect lessened upon soils which contain little vegetable matter.

4°. In the compost form the same quantity of lime acts more immediately. While lying in a state of mixture those chemical changes which lime either induces or promotes have already to a certain extent taken place, and thus the sensible effect of the lime becomes apparent in a shorter time after it has been laid upon the land.

5°. This is still more distinctly the case when, besides earthy matter, decayed vegetable substances, ditch scourings, and other refuse are mixed with the lime. The experience of every practical man has long proved how very much more enriching such composts are, and more obvious in their effects upon the soil, than the simple application of lime alone.

6°. It is stated as the result of extended trial in Flanders and in parts of France, that a much smaller quantity of lime laid on in this form will produce an equal effect. For this, one cause may be, that the rains are prevented from acting upon the mass of compost as they would do upon the open soil—in washing out either the lime itself or the saline substances which are produced during its contact with the earthy and vegetable matter with which it is mixed.

7°. The older the compost the more fertilizing is its action. This fact is of the same kind with that generally admitted in respect to the action of marls and unmixed lime—that it is more sensible in the second year, or in the second rotation, than in the first.

In conclusion, it may be stated that this form of application is especially adapted to the lightest and driest soils, and to such as are poorest in vegetable matter. In this form, lime has imparted an unexpected fertility even to the white and barren sands of the *Landes* (Puvis), and upon the dry hills of Derbyshire it has produced an almost equal benefit.

§ 14. *When ought lime to be applied?*

This question may refer either to the period in the lease, in the rotation, or of the year in which lime may most beneficially be laid upon the land. We have already considered this point in so far as it refers to the lease, while discussing the propriety of applying lime in large or in small doses.

In regard to the period of the year and of the rotation, there are three principles by which the procedure of the practical man ought chiefly to be directed.

1°. *That lime takes some time to produce its known effects upon the soil.*—It ought, therefore, to be applied as long as possible before the crop is sown. That is, in the early autumn, where either winter or spring corn is about to be sown,—on the naked fallow where the land is allowed to be at rest for a year,—or on the grass fields before breaking up, where the pasture is to be immediately succeeded by corn.

2°. *That quick-lime expels ammonia from decomposed and fermenting manure.*

When such manure, therefore, is applied to the land as it is in all our well-farmed districts, quick-lime should not be so laid upon the land as to come into immediate contact with it. If both *must* be applied in the same year, they should be laid on at periods as distant from each other as may be convenient, or if this necessity does not exist, the lime should be spread either a year before or a year after the period in the rotation at which the manure is usually applied.

It is for this reason, as well as for the other already stated (1°), that lime is applied to the naked fallow, to the grass before breaking up, or along with the winter wheat after a green crop which has been aided by fermented manure. When ploughed into the fallow, or spread upon the grass, it has had time to be almost completely converted into the mild state (that of carbonate), before the manure is laid on. In this mild state it has no sensible effect in expelling the ammonia of decomposing manure. Again, when it is applied in autumn along with, or immediately before the seed, the volatile or ammoniacal part of the manure has already been expended in nourishing the green crop, so that loss can rarely accrue from the admixture of the two at this period of the rotation.

The excellent elementary work of Professor Lowe* contains the following remark:—"It is not opposed to theory that lime should be applied to the soil at the same time with dung and other animal and vegetable substances, as is frequent in the practice of farmers." This is strictly correct only in regard to marls, lime-sand, &c., or to perfectly mild lime, any of which may be mixed, without loss, with manure in any state. Of quick or caustic lime it is correct only when the animal or vegetable matter has not yet begun to ferment. With *recent* animal or vegetable matter quick-lime may be mixed up along with earth into a compost, not only without the risk of much loss, but with the prospect of manifest advantage.

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* *Elements of Practical Agriculture, third edition*, p. 63.

3°. *That quick-lime hastens or revives the decomposition of inert organic matter.*—This fact also indicates the propriety of allowing the lime as much time as possible to operate before a crop is taken from land in which organic matter already abounds. Or where fermenting manure is added, it advises the farmer to wait till spontaneous decomposition becomes languid, when the addition of lime will bring it again into action and thus maintain a more equable fertility.

In a work upon soils, which I have frequently commended to your notice,* you will find the following observations:—"Writers on agriculture have stated that lime hastens the decay of vegetable matter, whereas the fact is, that it retards the process of the decomposition of vegetable matter. If straw of long dung be mixed with slaked lime, it will be preserved; while if mixed with an equal portion of earth, the earth will hasten its decay." The two facts stated in this last sentence are, I believe, correct, yet it is nevertheless consistent both with theory and with universal observation, that lime *in the soil* promotes the decomposition of organic matters, both animal and vegetable. This will appear more clearly when we come to study the precise nature of the action of lime upon organic substances in general.

The above remarks, in regard to the best time for applying lime, refer chiefly to *quick-lime*, the state in which, in this country, it is so extensively used. Marls and shell-sands can cause no loss when mixed with the manure, and therefore may with safety be laid on at any period of the rotation. The same remark applies with greater force to the lime composts. These may be used precisely in the same way as, and even instead of, the richer manures—may be laid, without risk, upon grass lands of any quality, and at any period—or as a top dressing on the young corn in spring, when the grass and clover seeds are sown by which the corn crop is to be succeeded. And as the compost acts more speedily than lime in any other form, it is especially adapted for immediate application to the crop it is intended to benefit. To wet lands also, it is well suited, and to such as are subject to much rain, by which, while the surface is naked, the soluble matters produced in the soil are likely to be very much washed away.

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* Morton "*On Soils*," third edition, p. 181

§ 15. *Of the effects produced by lime.*

The effects of pure lime upon the land, and upon vegetation, are *ultimately* the same, whether it be laid on in the state of hydrate or of carbonate. If different varieties produce unlike effects, the quantity of lime applied being the same, it is because in nature lime is always more or less mixed with other substances which are capable of modifying the effects which pure lime would alone produce. The special effects of marls, &c., when they differ from those of burned lime, are to be ascribed to the presence of such admixtures. In general, however, the chemical action of the marls and calcareous sands is precisely the same in kind as that of lime in the burned and slaked state, and so far the effects which we have already seen to be produced by marls (Part III. p. 110), represent also the general effects of lime in any form.

These general effects may be considered in reference to the land on which it is laid, and to the crops which are, or *may be*, made to grow upon it.

I.—EFFECTS OF LIME UPON THE LAND.

Pure lime, like the marls, produces both a mechanical and a chemical effect upon the soil. The former is constant with all varieties of tolerably pure lime, and is easily understood. It opens and renders freer such soils as are stiff and clayey, while it increases the porosity of such as are already light and sandy. To the former its mechanical action is almost always favourable, to the latter not unfrequently the reverse.

From its chemical action the benefits which follow the use of lime are chiefly derived. These benefits are principally the following:—

1°. It increases the fertility of all soils in which lime does not already abound, and especially adds to the productiveness of such as are moist or contain much inert vegetable matter.

2°. It enables the same soils to produce crops of a superior *quality* also. Land which, unlimed, will produce only a scanty crop (3 or 4 fold) of rye, by the addition of lime alone, will yield a 6 or 7 fold return of *wheat*. From some clays, also, apparently unfit to grow corn, it brings up luxuriant crops.

3°. It increases the effect of a given application of manure; calls into action that which, having been previously added, appears to lie dormant; and, though as we have already seen (Part III. p. 128), manure must be plentifully laid upon the land, after it has been well limed, yet the same degree of productiveness can still be maintained at a less cost of manure than where no lime has been applied.

4°. As a necessary result of these important changes, the money value and annual return of the land is increased, so that tracts of country which had let with difficulty for 5*s*. an acre, have in many localities been rendered worth 30s. or 40s. by the application of lime alone (Sir J. Sinclair).

II.—EFFECTS OF LIME ON THE PRODUCTIONS OF THE SOIL.

1°.—*It alters the natural produce of the land*, by killing some kinds of plants and favouring the growth of others, the seeds of which had before lain dormant. Thus it destroys the plants which are natural to silicious soils and to moist and marshy places. From the corn-field it extirpates the corn-marigold (*chrysanthemum segetum*),* while, if added in excess, it encourages the red poppy, the yellow cow-wheat (*melampyrum pratense*), and the yellow rattle (*rhinanthus crista galli*), and when it has sunk, favours the growth of the troublesome and deep-rooted coltsfoot.

Similar effects are produced upon the natural grasses. It kills heath, moss, and sour and benty† (*agrostis*) grasses, and brings up a sweet and tender herbage, mixed with white and red clovers, more greedily eaten and more nourishing to the cattle. Indeed all fodder, whether natural or artificial, is said to be sounder and more nourishing when grown upon land to which lime has been abundantly applied. On benty grass the richest animal manure often produces little improvement until a dressing of lime has been laid on.

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* Bönninghausen.

† In Liddisdale, on the Scottish border, is a large tract of land in what is

It is partly in consequence of the change which it thus produces in the nature of the herbage, that the application of quick-lime to old grass lands, some time before breaking up, is found to be so useful a practice. The coarse grasses being destroyed, *tough* grass land is opened and softened, and is afterwards more easily worked, while, when turned over by the plough, the sod sooner decays and enriches the soil. It is another advantage of this practice, however, that the lime has time* to diffuse itself through the soil, and to induce some of those chemical changes by which the succeeding crops of corn are so greatly benefitted.

2°. *It improves the quality of almost every cultivated crop.* Thus, upon limed land,

a. The grain of the corn crops has a thinner skin, is heavier, and yields more flour, while this flour is said also to be richer in gluten. On the other hand, these crops, after lime, run less to straw, and are more seldom laid. In wet seasons (in Ayrshire) wheat preserves its healthy appearance, while on unlimed land, of equal quality, it is yellow and sickly. A more marked improvement is said also to be produced both in the quantity and in the quality of the spring-sown than of the winter-sown crops (Puvis).

b. Potatoes grown upon all soils are more agreeable to the taste and more mealy after lime has been applied, and

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there called *flying bent*, not worth more than 3s. an acre. If surface-drained and limed at a cost of £2 to £3 an acre, this becomes worth 12s. an acre for sheep pasture. An intelligent and experienced border farmer assures me that such land would *never forget* 40 to 60 bushels of lime per acre.

* A comparatively long period is sometimes permitted to elapse before the grass land is broken up after liming. Thus at Netherby, "lime or compost is always applied to the third year's pasture, which is renovated by it, and in two or three years breaks up admirably for oats."

this is especially the case on heavy and wet lands, which lie still undrained.

c. *Turnips* are often improved both in quantity and in quality when it is laid on in preparing the ground for the seed. It is most efficient, and causes the greatest saving of farm-yard manure where it is applied in the compost form, and where the land is already rich in organic matter of various kinds.

d. *Peas* are grown more pleasant to the taste, and are said to be more easily *boiled soft*. Both beans and peas also yield more grain.

e. *Rape*, after a *half*-liming and manuring, gives extraordinary crops, and the same is the case with the *colsa*, the seed of which is largely raised in France for the oil which it yields.

f. On *flax* alone it is said to be injurious, diminishing the strength of the fibre of the stem. Hence, in Belgium, flax is not grown on limed land till seven years after the lime has been applied.

3°. *It hastens the maturity of the crop.*—It is true of nearly all our cultivated crops, but especially of those of corn, that their full growth is attained more speedily when the land is limed; and that they are ready for the harvest from 10 to 14 days earlier. This is the case even with buckwheat, which becomes sooner ripe, though it yields no larger a return, when lime is applied to the land on which it is grown.

4°. The liming of the land is the harbinger of health as well as of abundance. It salubrifies no less than it enriches the well cultivated district. I have already drawn your attention (Part III. p. 12) to this as one of the incidental results which follow the skilful introduction of the drain over large tracts of country. Where the use of lime and of the drain go together it is difficult to say how much of the increased healthiness of the district is due to the one improvement, and how much to the other. The lime arrests the noxious effluvia which tend to rise more or less from every soil at certain seasons of the year, and decomposes them or causes their elements to assume new forms of chemical combination, in which they no longer exert the same injurious influence upon animal life. How beautiful a consequence of skilful agriculture, that the health of the community should be promoted by the same methods which most largely increase the produce of the land! Can you doubt that the All-benevolent places this consequence so plainly before you, as a stimulus to further and more general improvement—to the application of other knowledge still to the amelioration of the soil?

§ 16. *Circumstances by which the effects of lime are modified.*

These effects of lime are modified by various circumstances. We have already seen that the quantity which must be applied to produce a given effect, and the form in which it will prove most advantageous are, in a great measure, dependant upon the dryness of the soil, upon the quantity of vegetable matter it contains, and on its stiff or open texture. There are several other circumstances, however, to which it is proper still to advert. Thus

1°. Its effects are greatest when well mixed with the soil, and *kept near the surface within easy reach of the atmosphere.* The reason of this will hereafter appear.

2°. On arable soils of the same kind and quality, the effects are greatest upon such as are newly ploughed out, or upon subsoils just brought to day. In the case of subsoils, this is owing partly to their containing naturally very little lime, and partly to the presence of noxious ingredients, which lime has the power of neutralizing. In the case of surface soils newly ploughed out, the greater effect, in addition to these two causes, is due also to the large amount of vegetable and other organic matter which has gradually accumulated within them. It is the presence of this organic matter which has led to the establishment of the excellent practical rule—"*that lime ought always to precede putrescent manures when old leys are broken up for cultivation.*"

3°. Its effects are greater on certain geological formations than on others. Thus it produces much effect on drifted (diluvial) sands and clays—on the soils of the plastic and wealden clays (Part II. p. 356)—on those of the new and old-red sand-stones, of the granites, and of many slate-rocks—and, generally, on the soils formed from all rocks which contain little lime, or from which the lime may have been washed out during their gradual degradation.

On the other hand, it is often applied in vain to the soils of the oolites (Part II. p. 359), and other calcareous formations, because of the abundance of lime already present in them. The advantage derived from chalking thin clay soils resting immediately upon the chalk rock (Part II. p. 357, and Part III. p. 112), is explained by the almost entire absence of lime from these soils. The clay covering of the chalk wolds has probably been formed, not from the ruins of the chalk rock itself, but from the deposit of muddy waters, which rested upon it for some time before those localities became dry land.

4°. Lime produces a greater *proportional improvement* upon poor soils than on such as are richer (Dr. Anderson). This also is easily understood. It is of poor soils in their *natural state* of which Dr. Anderson speaks.* In this state they contain a greater or less quantity of organic matter, but are nearly destitute of lime, and hence are in the most favourable condition for being benefitted by a copious liming. Experience has proved that by this one operation such land may be raised in money value eight times, or from 5s. to 40s. per acre; but no practical man would expect that arable land already worth £2 per acre could, by liming or any other single operation become worth £16 per acre of annual rent. The greater proportional improvement produced upon poor lands by lime is only an illustration, therefore, of the general truth—that on poor soils the efforts of the skilful improver are always crowned with the earliest and most apparent success.

5°. In certain cases, the addition of lime, even to land in good cultivation, and according to the ordinary and approved practice of the district, produces no effect whatever. This is sometimes observed where the custom prevails, as in some parts of Ayrshire and elsewhere, to apply lime along with every wheat crop (Part III. p. 126), and on such farms especially where the land is of a lighter quality. Where from 40 to 60 bushels of lime are added at the end of each rotation of 4 or 5 years, the land may soon become so saturated with lime that a fresh addition will produce no sensible effect. Thus Mr. Campbell, of Cragie, informs me of a trial made by an intelligent farmer in his neighborhood where alternate ridges only were limed without any sensible difference being observed. No result could show more clearly than this—that for one rotation at least the expense of lime might be saved, while at the same time the land would run the less risk of exhaustion. Another fact mentioned by Mr. Campbell proves the soundness of this conclusion. The lime never fails to produce obvious benefit where the land is allowed to be 4 or 5 years in grass—where it is applied, that is, only once in 8 or 9 years. The fair inference is, therefore, that in this district as well as in others where similar effects are observed—too much lime is habitually added to the land, whereby not only is a needless expense incurred, but a speedier exhaustion of the soil is insured. Good husbandry, therefore, indicates either the application of a smaller dose at the recurrence of the wheat crop—or the occasional omission of lime altogether for an entire rotation. The practical farmer cannot have a better mode of ascertaining when his land is thus fully supplied with lime—than by making the trial upon alternate ridges, and marking the effect.

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* "I never met," he says, "with a poor soil in its *natural state*, which was not benefitted in a very great degree by calcareous matter when administered in proper quantities. But I have met with several rich soils, which were fully impregnated with dung, on which lime applied in any quantity produced not the smallest sensible effect."

6°. On poor arable lands, which are *not* naturally so, but which are worn out or exhausted by repeated liming and cropping, lime produces no good whatever* (Anderson, Brown, Morton). Such soils, if they do not already abound in lime, are, at least, equally destitute of numerous other kinds of food, organic and inorganic, by which healthy plants are nourished,—and they are only to be restored to a fertile condition by a judicious admixture of all. This truth is confirmed by the practical observation, that on soils so exhausted farm-yard manure along with the lime does not produce the same good results as in other cases. *All* that the soil requires is not supplied in sufficient abundance by these two substances laid on alone.

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* "It is scarcely practicable to restore fertility to land, even of the best natural quality, which has been thus abused; and thin moorish soils, after being exhausted by lime, are not to be restored." (Brown).

7°. On lands of this kind, and on all in which vegetable matter is wanting, lime may even do harm to the immediate crop. It is apt to *singe* or *burn* the corn sown upon them (Brown)—an effect which is probably chemical, but which may in part be owing to its rendering more open and friable soils already by long arable culture too open already (Morton).

8°. A consideration of the circumstances above adverted to explains why, in some districts, and even in some whole provinces, the use of lime in any form should be condemned and even entirely given up. The soil has been impoverished through its unskilful application—or, by large admixtures of lime or marl for a series of years, the soil has been so changed as to yield no adequate return for new additions. Thus for a generation or two the practices of liming and marling are abandoned, to be slowly and reluctantly resumed again, when natural causes have removed the lime from the soil, and produced an accumulation of those other substances which, when associated with it, contribute to the productiveness of the land.

§ 17. *Effects of an over-dose of lime.*

There are several effects which are familiar to the practical man as more or less observable when lime in any form is laid too lavishly upon the land. Thus

1°. It is rendered so loose by an overdose as to be capable of holding no water (Kames). Upon stiff clays a very large quantity indeed will be required to produce this effect.

2°. By an overdose of quick-lime the land is hardened to such a degree as to be impervious to water or to the roots of plants. Several parts of the Carse of Gowrie are thus rendered so hard as to be unfit for vegetation (Kames).* This effect will be observed only in soils which are naturally wet and undrained, or where much rain has fallen and lingered on the land after the lime has been applied (Part III, p. 131).

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* Lord Kames's *Gentleman Farmer*, edit. 1802.

3°. But the most injurious effect of an over-liming, whether it be laid on at one or at successive periods, is the exhaustion by which it is succeeded. "An overdose of shell-marl," says Lord Kames, "laid perhaps an inch thick, produces for a time large crops, but at last renders the soil capable of bearing neither corn nor grass, of which there are many examples in Scotland." The same is true of lime in any form. The increased fertility continues as long as there remains an adequate supply of organic (animal and vegetable) matter in the soil, but as that disappears the crops every year diminish both in quantity and in quality.

An interesting illustration of this exhausting power of lime is afforded by the observed effects of long-continued marling upon certain poor soils in the province of Isere, in France. The marl there employed is a sandy marl, containing from 30 to 60 per cent. of carbonate of lime—very much like the lime-sand of Ireland or the shell-sand of the Western Islands already described (Part III., p. 107). A layer of this marl one-third of an inch thick, applied at intervals to a soil producing in its natural state only a *three-fold return of rye* every other year, causes it to yield for the first 10 or 12 years an *eight-fold return of wheat*. But after 40 years marling, the farmers now complain that the land will give only a four-fold return of wheat. But the cause of this reduction is to be found in the constant cropping with corn, in the growing of no green crops, and in *the addition of no manure*. Yet even with this treatment the land is still more productive than before the marling was commenced. It produces four returns instead of three, and it grows wheat where before only rye would thrive and ripen.

From the possession of this exhausting property has arisen the almost universally diffused proverb, that *lime enriches the fathers but impoverishes the sons*. The fault, however, is not in the lime, but in the improvident fathers, who in this case, as in so many others, exhaust and inconsiderately squander the inheritance of their sons. If care be taken to keep up the supply of organic matter in the soil—by copious additions of manure or otherwise (Part III., p. 127)—lime may be added freely and a system of high farming kept up, by which both the present holder of the land, and his successor, will be equally benefitted.

The opinion expressed by some of the highest authorities among practical men, that too much lime *cannot* be added, provided the soil abound sufficiently in vegetable matter, may perhaps be rather over-stated; but it undoubtedly embodies the result of long-continued general observation—that the exhausting effect of lime may be postponed indefinitely by a liberal management of the land.*

§ 18. *Length of time during which lime acts.*

It is the fate of nearly all the superficial improvements of the soil, that they are only temporary in their duration. The action of lime ceases after a time, and the land returns to its original condition. The length of time which must elapse before this takes place will depend, among other circumstances, upon the quantity of lime added to, or originally contained in, the soil—upon the kind of cropping to which it is subjected—on the nature of the soil itself—on the slope and exposure and natural moisture of the land, and on the climate in which it is situated.

We have seen that on the arable lands of the south of Scotland, 20 years is the longest period during which the doses there applied act beneficially upon the crops—while in other parts of the country renewed applications are considered necessary at much shorter intervals. Mr. Dawson, of Frogden, who introduced the practice of liming into the Border counties of Scotland, observed that, when harrowed in with the grass seeds, its effect in improving the subsequent pasture was sensible for 30 years after. A heavy marling or chalking in the Southern and Midland counties of England is said also to last for 30 years,* and the same period is assigned to the sensible effect of the ordinary doses of lime-sand in Ireland, and of shell-sands and marls in several parts of France.

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* In Germany the necessary union of manure and marl is in the mouth of every peasant—

——————Ohne mist
Ist das Geld für mergeln verquist.

The effect of the lime lessens gradually, and though at the end of an assignable number of years it becomes almost insensible, yet it does not altogether cease till a much later period. This period is in some cases so protracted that intelligent practical men are in many districts to be met with who believe—that certain grass lands would *never* forget a good dose of lime (Part III., p. 137, note).

§ 19. *Of the sinking of lime into the soil.*

One of the causes of this gradual diminution of the action of lime is to be found in the singular property it possesses of slowly sinking into the land, until it almost entirely disappears from the surface soil. It has been long familiar to practical men, that when grass lands, which have been limed on the sward, are after a time broken up, a white layer or band of lime is seen at a greater or less depth beneath the surface, but lodging, generally, where it has attained its greatest depth, between the upper, loose and fertile, and the lower, more or less impervious and unproductive soil. In arable lands the action of the plough counteracts this tendency in some measure, bringing up the lime again from beneath, and keeping it mixed with the surface mould. Yet, through ploughed land it sinks at length, especially where the ploughing is shallow, and even the industry of the gardener can scarcely prevent it from descending beyond the reach of his spade.

The chief cause of this sinking is to be found in the extreme minuteness of the particles into which slaked lime naturally falls. If a portion of slaked lime be mixed with water it forms a milky mixture, in which some lime is dissolved, but much more is held in suspension in an extremely divided state. When this milk is allowed to stand undisturbed, the fine particles subside very slowly, and are easily again disturbed, but if thrown upon a filter they are arrested immediately, and the lime-water passes through clear. Suppose these fine particles to be mixed with the soil, and the rain to fall upon them, it will carry them downwards through the pores of the soil till the close subsoil acts the part of a filter, and arrests them. This tendency to be washed down is common not only to lime but to *all minutely divided earthy matter of a sufficiently incoherent nature.* Hence the formation of that more or less impervious layer of finely divided matter which so often forms the subsoil beneath free and open surface soils. And that lime should appear alone or chiefly to sink on any cultivated field, may arise from this circumstance— that the continued action of the rains had long before carried downwards the finer incoherent particles of other kinds which existed naturally in the soil, and therefore could find little else but the lime on which this action could be exercised.

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* Applied at a cost of 30s. to 50s. per acre, according to the locality.—Mr. Pusey, *Royal Agricultural Journal*, iii., p. 185.

This explanation is satisfactory enough in the case of light and open soils, which are full of pores, but it appears less so in regard to stiff clays and to loamy soils which are not only close and apparently void of pores, but seem themselves to consist of particles in a sufficiently minute state of division to admit of their being carried down by the rains in an equal degree with lime itself. This difficulty induced Lord Dundonald to suspect the agency of some chemical principle in producing the above effect.* As the lime, however, is unchanged after it has descended, is still in a powdery state, and exhibits no appearance of having been dissolved, it is difficult to imagine any chemical action by which such a sinking could have been brought about.

It is possible that in grass lands the earth-worms, which contribute so much to the gradual production of a fine mould, may, by bringing up the other earthy matters only, contribute to the apparent sinking of the lime, as well as of certain other top-dressings.*

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* "In clayey and loamy soils, which are (?) equally diffusible with lime, and nearly of the same specific gravity, the tendency which lime has to sink cannot be accounted for simply on mechanical principles."—Lord Dundonald's *Agricultural Chemistry*, p. 45.

The effects of this sinking are to remove the lime from the surface soil, and to form a layer of calcareous matter which in wet or impervious bottoms will harden and form a more or less solid bed or *pan*, through which the rains and roots refuse to penetrate, and which the subsoil plough in some districts can tear up with difficulty. On our stiffer soils it encourages the growth of the troublesome colts-foot, and in the open ditches of the wholesome water-cress.

The practical remedies for this sinking are of two kinds:

1°. The ploughing of a deeper furrow, and hence one of the benefits which in many localities follow the use of the trench plough (Part III., p. 129).

2°. The sowing of deep-rooted and lime-loving crops, such as lucerne and sainfoin, which in such soils not only thrive, but bring up in their stems, and restore to the surface a portion of the lime which had previously descended, and thus make it available to the after-crops.

§ 20. *Why liming must be repeated.*

Lime which sinks, as above described, does not wholly escape from the soil, but may by judicious management be again brought to the surface. Such a sinking, therefore, does not necessarily call for the addition of a fresh dose of lime, nor does it explain the reason why in practice the application of lime to the land must at certain intervals be every where repeated.

We have already seen that the influence of the lime we have laid upon our fields after a time gradually diminishes —the grass becomes sensibly less rich year by year, the crops of corn less abundant, the kind of grain it will ripen less valuable. Does the lime, you might ask, actually disappear from the soil, or does it merely cease to act? This question has been most distinctly answered by an experiment of Lampadius. He mingled lime with the soil of a piece of ground till it was in the proportion of 1.19 per cent. of the whole, and he determined subsequently, by analysis, the quantity of lime it contained in each of the three succeeding years.

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* See in a subsequent lecture the remarks *on laying down to grass*; also the Author's ELEMENTS OF AGRICULTURAL CHEMISTRY, p. 212.

	Carbonate of Lime.
The first year it contained - - -	1·19 per cent.
The second year - - - - - -	0·89 ...
The third year - - - - - - -	0·52 ...
The fourth year - - - - - -	0·24 ...*

There can be no question, therefore, that the lime gradually disappears or is removed from the soil.

The agencies by which this removal is effected are of several kinds.

1°. In some cases it sinks, as we have already seen, and escapes into the subsoil beyond the reach of the plough or of the roots of our cultivated crops.

2°. A considerable quantity of lime is annually removed from the soil by the crops which are reaped from it. We have already seen (Part II., p. 326) that in a four years' rotation of alternate green and corn crops the quantity of lime contained in the average produce of good land amounts to 248 lbs. This is equal to 60 lbs. of quick-lime or 107 lbs. of carbonate of lime *every year*. The whole of this, however, is not usually lost to the land. Part at least is restored to it in the manure into which a large proportion of the produce is usually converted. Yet a considerable quantity is always lost—escaping chiefly in the liquid manure and in the drainings of the dung-heaps—and this loss must be repaired by the renewed addition of lime to the land.

3°. But the rains and natural springs of water percolating through the soil remove, in general, a still greater proportion. While in the quick or caustic state, lime is soluble in pure water. Seven hundred and fifty pounds of water will dissolve about one pound of lime. The rains that fall, therefore, cannot fail, as they sink through the soil, to dissolve and carry away a portion of the lime so long as it remains in the caustic state.

Again, quick-lime, when mixed with the soil, speedily attracts carbonic acid, and becomes, after a time, converted into carbonate, which is nearly insoluble in pure water.

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* Schübler, *Agricultur Chemie*, ii. p. 141.

But this carbonate, as we have already seen (Part I., p. 62), is soluble in water impregnated with carbonic acid—and as the drops of rain in falling absorb this acid from the air, they become capable, when they reach the soil, of dissolving an appreciable quantity of the finely divided carbonate which they meet with upon our cultivated lands. Hence the water that flows from the drains upon such lands is always impregnated with lime, and sometimes to so great a degree as to form calcareous deposits in the interior of the drains themselves, where the fall is so gentle as to allow the water to linger a sufficient length of time in the soil.

It is impossible to estimate the quantity of lime which this dissolving action of the rains must gradually remove. It will vary with the amount of rain which falls in each locality, and with the slope or inclination of the land; but the cause is at once universal and constantly operating, and would alone, therefore, render necessary, after the lapse of years, the application of new doses of lime both to our pastures and to our arable fields.

4°. During the decay of vegetable matter, and the decomposition of mineral compounds, which take place in the soil where lime is present, new combinations are formed in variable quantities which are more soluble than the carbonate, and which therefore hasten and facilitate this washing out of the lime by the action of the rains. Thus chloride of calcium, nitrate of lime, and gypsum are all produced—of which the two former are eminently soluble in water—while organic acids also result from the decay of the organic matter, with some of which the lime forms readily soluble compounds (salts) easily removed by water.

The ultimate resolution of all vegetable matter in the soil into carbonic acid and water (Part I., p. 227) likewise aids the removal of the lime. For if the soil be every where impregnated with carbonic acid, the rain and spring waters that flow through it will also become charged with this gas, and thus be enabled to dissolve a larger portion of the carbonate of lime than they could otherwise do. Thus theory indicates, what I believe experience confirms, that a given quantity of lime will disappear the sooner from a field, the more abundant the animal and vegetable matter it contains.

§ 21. *Theory of the action of lime.*

Lime acts in two ways upon the soil. It produces a *mechanical* alteration which is simple and easily understood, and is the cause of a series of *chemical* changes, which are really obscure, and are as yet susceptible of only partial explanation.

In the finely divided state of quick-lime, of slaked lime, or of soft and crumbling chalk, it stiffens very loose soils, and opens the stiffer clays,—while in the form of limestone gravel or of shell sand, it may be employed either for opening a clay soil or for giving body and firmness to boggy land. These effects, and their explanation, are so obvious to you, that it is unnecessary to dwell upon them.

The purposes served by lime as a chemical constituent of the soil are at least of four distinct kinds.

1°. It supplies a kind of inorganic food which appears to be necessary to the healthy growth of all our cultivated plants.

2°. It neutralizes acid substances which are naturally formed in the soil, and decomposes or renders harmless other noxious compounds which are not unfrequently within reach of the roots of plants.

3°. It changes the inert vegetable matter in the soil, so as gradually to render it useful to vegetation.

4°. It causes, facilitates, or enables other useful compounds, both organic and inorganic, to be produced in the soil,—or so promotes the decomposition of existing compounds as to prepare them more speedily for entering into the circulation of plants.

These several modes of action it will be necessary to illustrate in some detail.

§ 22. *Of lime as the food of plants.*

In considering the chemical nature of the ash of plants (Part II. pp. 318 to 329), we have seen that lime in all cases forms a considerable proportion of its whole weight. Hence the reason why lime is regarded as a necessary food of plants, and hence also one cause of its beneficial influence in general agricultural practice.

The quantity of pure lime contained in the crops produced upon one acre during a four years' rotation amounts, on an average, to 242 lbs.* which are equal to about 430 lbs. (say 4 cwt.) of carbonate of lime, in the state of marl, shell-sand, or lime-stone gravel. It is obvious, therefore, that one of the most intelligible purposes served by lime, as a chemical constituent of the soil, is to supply this comparatively large quantity of lime, which in some form or other must enter into the roots of plants.

But the different crops which we grow contain lime in unlike proportions. Thus the average produce of an acre of land under the following crops contains of lime—

		Grain or roots.	Straw or tops.	Total.
Wheat	(25 bush.)	1·5	7·2	8·7 lbs.
Barley	(38 bush.)	2·1	12·9	15 lbs.
Oats	(50 bush.)	2·5	5·7	8·2 lbs.
Turnips	(25 tons)	45·8	93·0	138·8 lbs.
Potatoes	(9 tons)	6·6	259·4	266·0 lbs.
Red Clover	(2 tons)	—	126·0	126·0 lbs.
Rye grass	(2 tons)	—	33·0	33·0 lbs.

These quantities are not constant, and wheat especially contains much more lime than is above stated, when it is grown upon land to which lime has been copiously applied. But the very different quantities contained in the several crops, as above exhibited, show that one reason *why lime favours the growth of some crops more than others* is, that some actually take up a larger quantity of lime as food. These crops, therefore, require the presence of lime in greater proportion in the soil, in order that they may be able to obtain it so readily that no delay may occur in the performance of those functions or in the growth of those parts to which lime is indispensable.

§ 23. *The chemical action of lime is exerted* CHIEFLY *upon the organic matter of the soil.*

There are four circumstances of great practical importance in regard to the action of lime, which cannot be too carefully considered in reference also to the theory of its operation. These are—

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* See Part II. p. 396.

1°. That lime has little or no effect upon soils in which organic matter is deficient.

2°. That its apparent effect is inconsiderable during the first year after its application, compared with that which it produces in the second and third years.

3°. That its effect is most sensible when it is kept near the surface of the soil, and gradually becomes less as it sinks towards the subsoil. And

4°. That under the influence of lime the organic matter of the soil disappears more rapidly than it otherwise would do, and that after it has thus disappeared fresh additions of lime produce no further good effect.

It is obvious from these facts, that *in general* the main beneficial purpose served by lime is to be sought for in the nature of its chemical action upon the organic matter of the soil—an action which takes place slowly, which is hastened by the access of air, and which causes the organic matter itself ultimately to disappear.

§ 24. *Of the forms in which organic matter usually exists in the soil, and the circumstances under which its decomposition may take place.*

I.—The organic matter which lime thus causes to disappear is presented to it in one or other of five different forms:

1°. In that of recent, often green, moist, and undecomposed roots, leaves, and stems of plants.

2°. In that of dry, and still undecomposed, vegetable matter, such as straw.

3°. In a more or less decayed or decaying state, generally black or brown in colour—and often in some degree soluble in water.

4°. In what is called the *inert* state, when spontaneous decay ceases to be sensibly observed. And

5°. In the state of chemical combination with the earthy substances—with the alumina for example, and with the lime or magnesia—already existing in the soil.

Upon these several varieties of organic matter lime acts with different degrees of rapidity.

II.—The final result of the decomposition of these several forms of organic matter, when they contain no nitrogen, is their conversion into carbonic acid and water only (Part I. p. 227). They pass, however, through several intermediate stages before they reach this point—the number and rapidity of which, and the kind of changes they undergo at each stage, depend upon the circumstances under which the decomposition is effected. Thus the substance may decompose—

1°. *Alone*, in which case the changes that occur proceed slowly, and arise solely from a new arrangement of its own particles. This kind of decomposition rarely occurs to any extent in the soil.

2°. *In the presence of water only.*—This also seldom takes place in the soil. Trees long buried in moist clays impervious to air, exhibit the kind of slow alteration which results from the presence of water alone, In the bottoms of lakes, ditches, and boggy places also, from which inflammable gases arise, water is the *principal* cause of the more rapid decomposition.

3°. *In the presence of air only.*—In nature organic matter is never placed in this condition, the air of our atmosphere being always largely mixed with moisture. In dry air decomposition is exceedingly slow, and the changes which dry organic substances undergo in it are often scarcely perceptible.

4°. *In the presence of both water and air.*—This is the almost universal condition of the organic matter in our fields and farm-yards. The joint action of air and water, and the tendency of the elements of the organic matter to enter into new combinations, cause new chemical changes to succeed each other with much rapidity. It will of course be understood that moderate warmth is necessary to the production of these effects.*

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* A familiar illustration of the conjoined efficacy of air and water in producing oxidation is exhibited in their action upon iron. If a piece of polished iron be kept in perfectly dry air it will not rust. Or if it be completely covered over with pure water in a well-stoppered bottle, from which air

5°. *In the presence of lime* or of some other alcaline substance (potash, soda, or magnesia).—Organic matter is often found in the soil in such a state that the conjoined action of both air and water are unable to hasten on its decomposition. A new chemical agency must then be introduced, by which the elements of the organic matter may again be set in motion. Lime is the agent which for this purpose is most largely employed in practical agriculture.

§ 25. *General action of alcaline substances upon organic matter.*

It is this action of alcaline matters upon the organic substances of the soil in the presence of air and water that we are principally to investigate.

When organic matter undergoes decay in the presence of air and water only, it first rots, as it is called, and blackens, giving off water or its elements chiefly, and forming *humus*—a mixture of humic, ulmic, and some other acids (Part III. p. 406) with decaying vegetable fibre. It then commences, at the expense of the oxygen of the air and of water, to form other more soluble acids (malic, acetic, lactic, crenic, mudesic, &c.), among which is a portion of carbonic—and, by the aid of the hydrogen of the water which it decomposes, one or more of the many compounds of carbon and hydrogen, which often rise up, as the marsh-gas does, and escape into the air (Part I. p. 228).

Thus there is a tendency towards the accumulation of acid substances of vegetable origin in the soil, and this is more especially the case when the soil is moist, and where much vegetable matter abounds. The effect of this superabundance of acid matter is, on the one hand, to arrest the

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is excluded, it will remain bright and untarnished. But if a polished rod of iron be put into an open vessel half full of water, so that one part of its length only is under the water—then the rod will begin very soon to rust at the surface of the water, and a brown ochrey ring of oxide will form around it, exactly where the air and water meet. From this point the rust will gradually spread upwards and downwards. So it is with the organic matter of the soil. Wherever the air and water meet, their decomposing action upon it, in ordinary temperatures, soon becomes perceptible.

further natural decay of the organic matter, and on the other to render the soil unfavourable to the healthy growth of young or tender plants.

The general effect of the presence of alcaline substances in the soil is to counteract these two evils. They combine with and thus remove the sourness of the acid bodies as they are formed. In consequence of this the soil becomes *sweeter* or more propitious to vegetation, while the natural tendency of the vegetable matter to decay is no longer arrested.

It is thus clear that an immediate good effect upon the land must follow either from the artificial application or from the natural presence of alcaline matter in the soil—while at the same time it will cause the vegetable matter to disappear more rapidly than would otherwise be the case. But the effect of such substances does not end here. They actually dispose or provoke—*pre-dispose* chemists call it—the vegetable matter to continue forming acid substances, in order that they may combine with them, and thus cause the organic matters to disappear more rapidly than they otherwise would do—in other words, they hasten forward the exhaustion of the vegetable matter of the soil.

Such is the general action of *all* alcaline substances. This action they exhibit even in close vessels. Thus a solution of grape sugar, mixed with potash, and left in a warm place, slowly forms *melassic acid*—while in cold lime-water the same sugar is gradually converted into another acid called the *glucic*. But in the air other acids are formed in the same mixtures, and the changes proceed more rapidly. Such is the case also in the soil, where the elements of the air and of water are generally at hand to favour the decomposition.

But the *nature* of the alcaline matter which is present determines also the rapidity with which such changes are produced. The most powerful alcaline substances—potash and soda—produce all the above effects most quickly; lime and magnesia are next in order, and the alumina of the clay soils, though much inferior to all of these, is far from being without an important influence.

Hence one of the benefits which result from the use of wood-ashes containing carbonate of potash, when employed in small quantities, and along with vegetable and animal manures, as they are in this country; but hence also the evil effects which are found to follow from the application of them in too large doses. Thus in countries where wood abounds, and where it is usual, as in Sweden and Northern Russia, to burn the forests and to lay on their ashes as manure, the tillage can be continued for a few years only. After one or two crops the land is exhausted, and must again be left to its natural produce.

§ 26. *Special effects of* CAUSTIC *lime upon the several varieties of organic matter in the soil.*

The effects of lime upon organic matter are precisely the same in kind as those of the alcalies in general. They are only less in degree, or take place more slowly, than when soda or potash is employed. Hence, the greater adaptation of lime to the purposes of practical agriculture.

1°. *Action of caustic lime alone upon vegetable matter.*—If the fresh leaves and twigs of plants, or blades and roots of grass, be introduced into a bottle, surrounded with slaked lime, and corked—they will slowly undergo a certain change of colour, but they may be preserved, it is said, for years, without exhibiting any striking change of texture (Mr. Garden). If dry straw be so mixed with slaked lime, it will exhibit still less alteration. In either case also the changes will be even less perceptible if, instead of *hydrate* of lime, the *carbonate* (or *mild* lime), in any of its forms, be mixed with these varieties of vegetable matter. On some other varieties of vegetable matter—such, for example, as are undergoing rapid decay, or have already reached an advanced stage of decomposition, —an admixture of slaked lime produces certain perceptible changes immediately, and mild lime more slowly, but these changes being completed, the tendency of *lime alone* is to arrest rather than to promote further *rapid* alterations. Hence, the following opinions of experienced practical observers must be admitted to be theoretically correct—in so far as they refer to the action of lime *alone*.

"If straw of long dung be mixed with slaked lime it will be preserved" (Morton).[*]

"Lime mixed in a mass of earth containing the live roots and seeds of plants will *not* destroy them" (Morton).[†]

"Sir H. Davy's theory, that lime dissolves vegetable matter, is given up; in fact, it hardens vegetable matter" (Mr. Pusey).[‡]

These opinions, I have said, are probably correct in so far as regards the unaided action of lime. They even express, with an approach to accuracy, what will take place in the interior of compost heaps of a certain kind, or in some dry soils; but that they cannot apply to the ordinary action of lime upon the soil is proved by the other result of universal observation, *that lime, so far from preserving the organic matter of the land to which it is applied, in reality wastes it*—causes, that is, or disposes it to disappear.

2°. *Action of caustic lime on organic matter in the presence of air and water.*—In the presence of air and water, when assisted by a favouring temperature, vegetable matter, as we have already seen, undergoes spontaneous decomposition. In the same circumstances lime promotes and sensibly hastens this decomposition,—altering the forms or stages through which the organic matter must pass—but bringing about more speedily the final conversion into carbonic acid and water. During its natural decay in a moist and open soil, organic matter gives off a portion of carbonic acid gas which escapes, and forms certain other acids which remain in the dark mould of the soil itself. When quick or slaked lime is added to the land, its first effect is to combine with these acids—to form carbonate, humate, &c., of lime—till the whole of the acid matter existing at the time is taken up. That portion of the lime which remains uncombined, either slowly absorbs carbonic acid from the air or unites with the carbonate already formed, to produce the known compound of hydrate with carbonate of lime*—waiting in this state in the soil till some fresh portions of acid matter are formed with which it may combine. But it does not inactively wait; it persuades and influences the organic matter to combine with the oxygen of the air and water with which it is surrounded, for the production of such acid substances —till finally the whole of the lime becomes combined either with carbonic or with some other acid of organic origin.

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[*] *On Soils*, 3rd edition, p. 181.

[†] Ibid.

[‡] *Royal Agricultural Journal*, iii., p. 212.

Nor at this stage are the action and influence of lime observed to cease. On the contrary, this result will, in most soils, be arrived at in the course of one or two years, while the beneficial action of the lime itself may be perceptible for 20 or 30 years. Hence there is much apparent ground for the opinion of Lord Kames, "that lime is as efficacious in its (so called) effete as in its caustic state." Even the more strongly expressed opinion of the same acute observer, "that lime produces little effect upon vegetables till it becomes effete"—derives much support from experience—since lime is known to have comparatively little effect upon the productiveness of the land till one or two years after its application, and this period, as I have said, is in most localities sufficient to deprive even slaked lime of all its caustic properties.

Of the saline compounds† which caustic lime thus forms, either immediately or ultimately, some, like the carbonate and humate, being very sparingly soluble in water, remain more or less permanently in the soil; others, like the acetate of lime, being readily soluble, are either washed out by the rains or are sucked up by the roots of the growing plants. In the former case they cause the removal of both organic matter and of lime from the land; in the latter they supply the plant with a portion of organic food, and at the same time with lime—without which, as we have frequently before remarked, plants cannot be maintained in their most healthy condition.

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* That compound, namely, which is produced when quick-lime slakes spontaneously in the air.—See Part III., p. 100.

† Saline compounds or salts are always formed when lime, magnesia, potash, soda, &c., combine with acids.

§ 27. *Action of mild (or carbonate of) lime upon the vegetable matter of the soil.*

The main utility of lime, therefore, depends upon its prolonged *after* action upon the vegetable matter of the soil. What is this action, and in what consists the benefits to which it gives rise?

In answering this question, it is of importance to observe that all the effects produced by alcaline matter in general—whether by lime or by potash—in the caustic state, are produced in *kind* also by the same substances in the state of carbonate. The carbonic acid with which they are united is retained by a comparatively feeble affinity, and is displaced with greater or less ease by almost every other acid compound which is produced in the soil. With this displacement is connected an interesting series of beautiful reactions, which it is of consequence to understand.

You will recollect that the great end which nature, so to speak, has in view, in all the changes to which she subjects organic matter in the soil, is to convert it—with the exception of its nitrogen—into carbonic acid and water. For this purpose it combines, at one time, with the oxygen of the air, while at another it decomposes water and unites with the oxygen or the hydrogen which are liberated, or with both to form new chemical combinations. Each of these new combinations is either immediately preliminary to or is attended by the conversion of a portion of the elements of the organic matter into one or other of those simpler forms of matter on which plants live. Now during these preliminary or preparatory steps, acid substances, as I have already explained, are among others constantly produced. With these acids, the carbonate of lime, when present in the soil, is ever ready to combine. But in so combining, it gives off the carbonic acid with which it is already united, and thus a continual, slow, evolution of carbonic acid is kept up as long as any undecomposed carbonate remains in the soil.

I do not attempt to specify by name the various acid substances which are thus formed during the oxidation of the organic matter, and which successively unite with the lime, because the entire series of interesting and highly important changes, which organic substances undergo in the soil, has as yet been too little investigated, to permit us to do more than speak in general terms of the nature of the chemical compounds which are most abundantly produced. Of two facts, however, in regard to them, we are certain—that they are simpler in their constitution than the original organic matter itself, from which they are derived—and that they have a tendency to assume still simpler forms, if they continue to be exposed to the same united action of air, water, and alcaline substances.

Hence the compounds which lime has formed with the acid substances of the soil, themselves hasten forward to new decompositions,—unite with more oxygen, liberate slowly portion after portion of their carbon in the form of carbonic acid, and of their hydrogen in the form of water—till at length the lime itself is left again in the state of carbonate, or in union with carbonic acid only. This residual carbonate begins again the same round of changes through which it had previously passed. It gives up its carbonic acid at the bidding of some more powerful organic acid produced in its neighbourhood, while this acid, by exposure to the due influences, undergoes new alterations till it also is finally resolved into carbonic acid and water.

Two circumstances are deserving to be borne in mind in reference to these successive decompositions—*first*, that in the course of them more soluble compounds of lime are now and then formed, some of which are washed out by the rains, and escape from the soil, while others minister to the growth of plants,—and *second*, that very much carbonic acid is produced as their final result—of which also part is taken up by the roots of plants, and part escapes into the air. Thus at every successive stage a portion of organic matter is lost to the soil. If this quantity be greater than that which is yearly gained in the form of roots or decayed leaves and stems of plants, or of manure artificially added, the soil will be gradually exhausted—if less, it will every year become more rich in vegetable matter.

It is also to be borne in mind that although, for the purpose of illustration, I have supposed the carbonate of lime first formed in the soil to be subsequently combined with other acids, which gradually decompose and leave it again in the state of carbonate,—yet it will rarely happen that the whole of the carbonate of lime in the soil will be in any of these new states of combination. In general a part of it only is thus at any one time employed in working up the acid substances produced. But it is necessary that it should be universally diffused through the soil in order that it may be every where at hand to perform the important part of its functions above explained. It is only where little lime is present, or where decaying vegetable matter is in exceeding abundance, that the whole of the carbonate can at one and the same time disappear (Part III., p. 119).

The changes, therefore, which lime and organic matter, supposed to be free from nitrogen, respectively undergo, and their mutual action in the soil, may be summed up as follows:—

1°. The organic matter, under the influence of air and moisture, spontaneously decomposes, and besides carbonic acid which escapes, forms also other acid substances which linger in the soil.

2°. With these acids the quick-lime combines, and either by its union with them or with carbonic acid from the air soon (comparatively) loses its caustic state.

3°. The production of acid substances by the oxidation of the organic matter—goes on more rapidly under the disposing influence of the lime, whether caustic or carbonated. These acids combine with the lime, liberating from it, when in the state of carbonate, a slow but constant current of carbonic acid, upon which plants at least partly live.

4°. The organic acid matter which thus unites with the lime continues itself to be acted upon by the air and water, aided by heat and light—itself passes through a succession of stages of decomposition, at each of which it gives off water or carbonic acid, retaining still its hold of the lime, till at last being wholly decomposed it leaves the lime again in the state of carbonate ready to begin anew the same round of change.

During this series of progressive decompositions, certain more soluble compounds of lime are formed, by which plants are in part at least supplied with this earth, and which with the aid of the rains carry off both lime and organic matter from the soil.

And, again, the more rapid the production of the acid substances which result from the union of the organic matter with oxygen, the more abundant in general also the production of those gaseous and volatile compounds which they form by uniting with hydrogen, so that, in promoting the formation of the one class of bodies, lime also favours the evolution of the other in greater abundance, and thus in a double measure contributes to the exhaustion of the soil.

The *disposing* action of lime to this twin form of decomposition, few varieties of organic matter can resist,—and hence arises the well-known efficacy of lime in resolving and rendering useful the apparently inert vegetable substances that not unfrequently exist in the soil.

§ 28. *Of the comparative utility of burned and unburned lime.*

Is there no advantage, then, you may ask, in using caustic or burned rather than carbonated or unburned lime? If the ultimate effects of both upon the land be the same, why be at the expense of burning? Among other benefits may be enumerated the following:—

1°. By burning and slaking, the lime is reduced to the state of an impalpable powder, finer than could be obtained by any available method of crushing. It can in consequence be diffused more uniformly through the soil, and hence a smaller quantity will produce an equal effect. This minute state of division also promotes in a wonderful degree the chemical action of the lime. In all cases chemical action takes place between exceedingly minute particles of matter, and among solid substances the more rapidly, the finer the powder to which they can be reduced. Thus a mass of iron or lead slowly rusts or tarnishes in the air, but if the mass of either metal be reduced to the state of an impalpable powder—which can be done by certain chemical means—it will take fire when simply exposed to the air at the ordinary temperature, and will burn till it is entirely converted into oxide. By mere mechanical division the apparent action of the oxygen of the air upon metals is augmented and hastened in this extraordinary degree—and a similar result follows when lime in an impalpable state is brought into contact with the vegetable matter upon which it is intended to act.

2°. The effect of burned lime is more powerful and more immediate than that of unburned lime in the form of chalk, marl, or shell sand. Hence it sooner neutralizes the acids which exist in the soil, and sooner causes that decomposition of vegetable matter of every kind to commence, upon which its efficacy, in a great degree, depends. Hence, when it can easily be procured, it is better fitted for sour grass or arable lands, for such as contain an excess of vegetable matter, and especially for such as abound in that dead or inert form of organic matter which requires a stronger stimulus—the presence of more powerful chemical affinities, that is—to bring it into active decomposition. In such cases, the lime has already done much good before it has been brought into the mild state—and remaining afterwards in this state in the soil, it still serves, in a great measure, the same slower after-purposes, as the original addition of carbonate would have done.

3°. Besides, if any portion of it, after the lapse of two or three years, still linger in the caustic state (Part III. p. 100), it will continue to provoke more rapid changes among the organic substances in the soil, than mild lime alone could have done.

4°. Further, quick-lime is soluble in water, and hence every shower that falls and sinks into the soil carries with it a portion of lime, so long as any of it remains in the caustic state. It thus reaches acid matters that lie beneath the surface, and alters and ameliorates even the subsoil itself.

5°. It is not a small additional recommendation of quick-lime, that by burning it loses about 44 per cent. of its weight, thus enabling nearly twice the quantity to be conveyed from place to place at the same cost of transport. This not only causes a direct saving of money,—as when the burned chalk of Antrim is carried by sea to the Ayrshire coasts—but an additional saving of labour also upon the farm,—where the number of hands and horses is often barely sufficient for the necessary work.

§ 29. *Action of lime on organic substances which contain nitrogen.*

I have hitherto, for the sake of simplicity, directed your attention solely to the action, whether immediate or remote, which is exercised by lime upon organic matter supposed to contain no nitrogen. Its action upon compounds in which nitrogen exists is no less beautiful and simple, perhaps even more intelligible and more obviously useful to vegetation.

There are several well known facts which it is here of importance for us to consider—

1°. That the black vegetable matter of the soil always contains nitrogen. Even that which is most inert retains a sensible proportion of it. It exists in dry peat to the amount of about 2 per cent. of its weight, and still clings to the other elements of the organic matter, even after it has undergone those prolonged changes by which it is finally converted into coal. Since nitrogen, therefore, is so important an element in all vegetable food, and so necessary in some form or other to the healthy growth and maturity of plants, it must be of consequence to awaken this element of decaying vegetable matter, when it is lying dormant, and to cause it to assume a form in which it can enter into and become useful to our cultivated plants.

2. That if vegetable matter of any kind be heated with slaked lime, the whole of the nitrogen it may contain, in whatever state of combination it may previously exist, will be given off in the form of ammonia. The same takes place still more easily if a quantity of hydrate of potash or of hydrate of soda be mixed with the hydrate of lime. Though it has not as yet been proved by direct experiment—yet I consider it to be exceedingly probable that

what takes place quickly in our laboratories, at a comparatively high temperature, may take place more slowly also in the soil, and at the ordinary temperature of the atmosphere.

3°. That when animal and vegetable substances are mixed with earth, lime, and other alcaline matters, in the so-called nitre beds (Part I., p. 242), ammonia and nitric acid are both produced, the quantity of nitrogen contained in the weight of these compounds extracted being much greater than was originally present in the animal and vegetable matter employed (Dumas). Under the influence of alcaline substances, therefore, *even when not in a caustic state*, the decay of animal and vegetable matter in the presence of air and moisture causes some of the nitrogen of the atmosphere to become fixed in the soil in the form of ammonia or of nitric acid. What takes place on the confined area of a nitre bed, may take place to some extent also in the wider area of a well limed and well manured field.

In the action of alcalies in the nitre bed, *disposing* to the production of nitric acid, we observe the same kind of agency, which we have already attributed to lime, in regard to the more abundant elements which exist in the vegetable matter of the soil. It gently persuades all the elements—nitrogen and carbon alike—to unite with the oxygen of air and water, and thus ultimately to form acid compounds with which it may itself combine.

The action of lime upon such organic matters containing nitrogen as usually exist in the soil, may, therefore, be briefly stated as follows :—

1°. These substances like all other organic matter undergo in moist air—and, therefore, in the soil—a spontaneous decomposition, the general result of which is the production of ammonia, and of an acid substance with which the ammonia may combine. This change is precisely analogous to that which takes place in such substances as starch and woody fibre, which contain no nitrogen. In each case, one portion of the elements unites with oxygen to produce an acid, the other with hydrogen to form a compound possessed of alcaline or indifferent properties. Thus,—

		With oxygen.	With hydrogen.
Vegetable matter	produces	Carbonic, ulmic, and other acids.	Marsh gas or other carburetted hydrogens.
Animal matter	produces	Carbonic, nitric, ulmic, and other acids.	Ammonia.

If the ammonia happen to be produced in larger relative quantity than the acids with which it is to combine, or if the carbonic be the only acid with which it unites, a portion of it may escape into the air. This rarely happens, however, in the soil, the absorbent properties of the earthy matters of which it consists being in most cases sufficient to retain the ammonia, till it can be made available to the purposes of vegetable life.

When caustic (hydrate of) lime is added to a soil in which ammonia exists in this state of combination with acid matter, it seizes upon the acid and sets the ammonia free. This it does with comparative slowness, however—for it does not at once come in contact with it all—and by degrees, so as to store it up in the pores of the soil till the roots of plants can reach it, or till it can itself undergo a further change by which its nitrogen may be rendered more fixed (Part III., p. 167.)

Carbonate of lime, on the other hand, still more slowly persuades the ammonia to leave the acid substances (ulmic, nitric ? &c.,) with which it is combined, and yielding to it in return its own carbonic acid, enables it in the state of soluble carbonate of ammonia to become more immediately useful to vegetation.

2°. But in undergoing this spontaneous decay even substances containing nitrogen reach at length a point at which decomposition appears to stop—an inert condition in which, though nitrogen be present as in peat, they cease sensibly to give it off in such a form or quantity as to be capable of ministering to vegetable growth. Here caustic lime steps in more quickly, and mild lime by slower degrees, to promote the further decay. It induces the carbonaceous matter to take oxygen from the air and from water and to form acids, and the nitrogen to unite with the hydrogen of the water for the production of ammonia—thus helping forward the organic matter in its natural course of decay, and enabling it to fulfil its destined purposes in reference to vegetable life.

3°. But the ammonia which is thus disengaged in the soil by decaying organic matter, though not immediately worked up, so to speak, by living plants, is not permitted to escape in any large quantity into the air. The soil, as I have already stated, is usually absorbent enough to retain it in its pores for an indefinite period of time. And as in nature and upon the earth's surface the elements of matter are rarely permitted to remain in a state of repose, the ammonia, though retained apparently inactive in the soil, is yet slowly uniting with a portion of the surrounding oxygen and forming nitric acid (Part I. p. 243, note.) When no other *base* is present, this nitric acid, as it is produced, unites with some of the ammonia itself which still remains, forming *nitrate of ammonia*—but if potash or lime be present within its reach, it unites with them in preference, and forms the *nitrate of potash or of lime.*

But lime, if present, is not an inactive spectator, so to speak, of this slow *oxidation* of ammonia. On the contrary, it promotes this final change, and by being ready to unite with the nitric acid as it forms, increases and accelerates its production, at the expense of the ammonia which it had previously been instrumental in evolving.

4°. One other important action of lime, by which the same compounds of nitrogen are produced in the soil, may in this place be most properly noticed. It is a chemical law of apparently extensive application, that when one elementary substance is undergoing a direct chemical union with a second *in the presence of a third*, a tendency is imparted to the third to unite also with one or with both of the other two, although in the same circumstances it would not unite with either, if present alone. Thus, when the carbonaceous matter of the soil is undergoing oxidation in the air—that is, combining with the oxygen of the atmosphere—it imparts a tendency to the nitrogen also to unite with oxygen, which when mixed with that gas alone* it has no known disposition to do. The result of this is the production of a small, and always a variable, proportion of nitric acid during the decomposition in the soil, of organic matter even, which itself contains no nitrogen.

Again, it is an equally remarkable chemical law, that elementary bodies which refuse to combine, however long we may keep them together in a state of mixture, will yet unite readily when presented to each other in what is called by chemists the *nascent* state—that is, at the moment when one or other of them is produced or is separated from a previous state of combination.

Thus when the organic matter of the soil decomposes water in the presence of atmospheric air, its carbon unites with the greater part of the oxygen and hydrogen which are set at liberty, and at the same time with more or less of the oxygen of the atmosphere—but at the same instant the nitrogen of the atmosphere, which is every where present, seizes a portion of the hydrogen and forms ammonia. Thus a variable, and in any one limited spot, a minute, but over the entire surface of the globe, a large quantity of ammonia is produced during the oxidation even of the purely carbonaceous portion of the organic matter of the soil.

Now in proportion as the presence of lime promotes this decay of vegetable and other organic matter in the soil—in the same proportion does it promote the production of ammonia and nitric acid, at the expense of the free nitrogen of the atmosphere, and this may be regarded as one of the valuable and constant purposes served by the presence of calcareous matter in the soil.

§ 30. *How these chemical changes directly benefit vegetation.*

You will scarcely, I think, inquire how all these interesting chemical changes which attend upon the presence of lime in the soil are directly useful to vegetation, and yet it may be useful shortly to answer the question.

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* The atmosphere consisting, as you will recollect, of nitrogen and oxygen (Part I., p. 38.)

1°. Lime combines with the acid substances already existing in the soil, and thus promotes the decomposition of vegetable matter which those acid substances arrest. The further decompositions which ensue are attended at every step by the production either of gaseous compounds—such as carbonic acid and light carburetted hydrogen—which are more or less abundantly absorbed by the roots and leaves of plants, and thus help to feed them—or of acid and other compounds, soluble in water, which, entering by the roots, bear into the circulation of the plant not only organic food but that supply of lime also which healthy plants require.

2°. The changes it induces upon substances in which nitrogen is present are still more obviously useful to vegetation. It eliminates ammonia from the compounds in which it exists already formed, and promotes its slow conversion into nitric acid, by which the nitrogen is rendered more fixed in the soil. It disposes the nitrogen of more or less inert organic matter to assume the form of ammonia and nitric acid, in which state experience has long shown that this element is directly favorable to the growth of plants. And

3°. It influences, in an unknown degree, the nitrogen of the atmosphere to become fixed in larger proportion in the soil, in the form of nitric acid and ammonia, than would otherwise be the case, and this it does both by the greater amount of decay or oxidation which it brings about in a given time, and by the *kind* of compounds which, under its influence, the organic matter is persuaded to form. The amount of nitrogenous food placed within reach of plants by this agency of lime will vary with the climate, with the nature of the soil, with its condition as to drainage, and with the more or less liberal and skilful manner in which it is farmed.

§ 31. *Why lime must be kept near the surface.*

Nor will you fail to see the important reasons why lime ought to be kept near the surface of the soil—since

1°. The action of lime upon organic matter is almost nothing in the absence of air and moisture. If the lime sink, therefore, beyond the constant reach of fresh air, its efficacy is in a great degree lost.

2°. But the agency of the light and heat of the sun, though I have not hitherto specially insisted upon their action—are scarcely less necessary to the full experience of the benefits which lime is capable of conferring. The light of the sun accelerates nearly all the chemical decompositions that take place in the soil—while some it appears especially to promote. The warmth of the sun's rays may penetrate to some depth, but their light can only act upon the immediate surface of the soil. Hence the skilful agriculturist will endeavor, if possible, to keep some of his lime at least upon the very surface of his arable land. Perhaps this influence of light might even be adduced as an argument in favor of the frequent application of lime in small doses, as a means of keeping a portion of it always within reach of the sun's rays; and this more especially on grass lands, to which no mechanical means can be applied for the purpose of bringing again to the surface the lime that has sunk.

There are, at the same time, as you will recollect, good reasons also why a portion of the lime should be diffused through the body of the soil, both for the purpose of combining with organic acids already existing there, and with the view of acting upon certain inorganic or mineral substances, which are either decidedly injurious, or by the action of lime may be rendered more wholesome to vegetation.

In order that this diffusion may be effected, and especially that lime may not be unnecessarily wasted where pains are taken by mechanical means to keep it near the surface, an efficient system of under drainage should be carefully kept up. Where the rains that fall are allowed to flow off the surface of the land, they wash more lime away the more carefully it is kept among the upper soil—but where a free outlet is afforded to the waters beneath, they carry the lime with them as they sink towards the subsoil, and have been robbed again of the greater part of it before they escape into the drains. Thus on drained land the rains that fall aid lime in producing its beneficial effects, while in undrained land they in a greater or less degree counteract it.

§ 32. *Action of lime upon the inorganic or mineral matter of the soil.*

Though the main general agency of lime is exerted, as we have seen, upon the organic matter it meets with, yet it often also produces direct chemical changes upon the mineral compounds existing in the soil, which are of great importance to vegetation. Thus

1°. Lime, either in the mild or in the caustic state, possesses the property of decomposing the sulphate of iron, which especially abounds in peaty soils, and in many localities so saturates the subsoil as to make it destructive to the roots of plants. Sprengel mentions a case where the first year's clover always grew well, while in the second year it always died away. This, upon examination, was found to be owing to the ferruginous nature of the subsoil, which caused the death of the plants as soon as the roots began to penetrate it.

When salts of iron exist in the soil, a dressing with lime will bring the land into a wholesome state without other aid. The lime will combine with the acid, and form gypsum, if it is the sulphate of iron that is present, while the *first* oxide of iron which is set free will, by exposure to the air, be converted into the *second* or red oxide, in which state this metal is no longer hurtful to vegetation.

When these salts are to be decomposed and removed from the subsoil, lime must be aided by the subsoil plough and the drain. Unless an outlet beneath be provided for the surface water, by which the rains may be enabled to wash away slowly the noxious substances from the subsoil, even the addition of a copious dose of lime will only produce a temporary improvement.

2°. Lime decomposes also the sulphates of magnesia and of alumina, both of which are occasionally found in the soil, and, being very soluble salts, are liable to be taken up by the roots in such quantity as to be hurtful to the growing plants. When soils which contain any of the three salts I have mentioned have once been limed or marled, it is in vain to add gypsum in the hope of favouring the clover crop, since the lime, in decomposing the sulphates, has already formed an abundant supply of this compound for all the purposes of vegetation.

3°. Among the earthy constituents of the soil, we have already seen that there often exist fragments of felspar and of other minerals derived from the granitic and trap rocks, which contain potash or soda in the state of *silicates*. These silicates we know to be slowly decomposed by the agency of the carbonic acid of the air (Part II., p. 305) and their alkali set free in a soluble state. This decomposition is said to be promoted by the presence of lime (Part III., p. 90.)

Again, the stalks of the grasses and the straw of the corn-bearing plants contain much silica in combination with potash and soda. In farm-yard manure, therefore, much of these silicates is present, and when mixed with the soil, their appears little reason to doubt that they are of much benefit to the growing crops. On these silicates, in the presence of carbonic acid and moisture, the lime acts as it does upon the mineral silicates. It aids in the liberation of the potash and soda, and thus promotes the performance of those important functions which these alkalies are destined to exercise in reference to vegetable growth (Part III., p. 41).

While the alkali is set free the lime itself combines with the silica, and hence one source of the silicate of lime which, as I have already mentioned to you (Part III., p. 118), usually exists in sensible quantity in our cultivated soils. It has been stated by Sprengel* as one reason why the addition of lime must be repeated so frequently upon some soils in which silica abounds, that an insoluble silicate of lime is formed, which is of no use to vegetation. But the silicates of lime are slowly decomposed by the agency of the carbonic acid of the air and of decaying vegetation, and to this cause in a previous lecture (Part II., p. 388), I have ascribed much of the fertile character of the trap and syenitic soils, and of their beneficial action when laid on as a manure.

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* *Lehre vom Dünger*, p. 310.

4°. Potash and soda exist to some extent in clay soils in combination with their alumina. The presence of lime has a similar influence in setting the alcalies free from this state of combination also.

5°. Alumina has the property of combining readily with many vegetable acids, and in the clay soils exercises a constant influence, similar in kind to that of lime and other alkaline substances, in persuading the organic matter to those forms of decay in which acid compounds are more abundantly produced. Hence, clay soils almost always contain a portion of alumina in combination with organic matter. This organic matter is readily given up to lime, and by the more energetic action of this substance is sooner made available to the wants of new races of plants.

6°. I shall bring under your notice only one other, but a highly important, decomposing action, which lime exercises in soils that abound in vegetable matter. In the presence of decaying organic substances the carbonate of lime is capable of slowly decomposing common salt, producing carbonate of soda and chloride of calcium. It exercises also a similar decomposing effect, even upon the sulphate of soda, and, according to Berthollet,* incrustations of carbonate of soda† are observed on the surface of the soil, wherever carbonate of lime and common salt are in contact with each other. If we consider that along all our coasts common salt may be said to abound in the soil, being yearly sprinkled over it by the salt sea winds—that generally, along the same coasts, the application of sulphates produces little sensible effect upon the crops, and that, therefore, in all probability they abound in the soil, derived, it may be, from the same sea spray—we may safely conclude, I think, that the decomposition now explained must take place extensively in all those parts of our island which are so situated, if lime in any of its forms either exists naturally or has been artificially added to the land. The same must be the case also in those districts where salt springs occur, and generally over the new red sand-stone formation, in which sea salt more especially occurs.

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* Dumas *Traite de Chemie*, ii., p. 334.

† Of *Trona* or *Natron*, which is a *sesqui* carbonate of soda.

And if we further consider the important purposes which the carbonate of soda thus produced may serve in reference to vegetation—that it may dissolve vegetable matter and carry it into the roots—that it may form soluble silicates, and thus supply the necessary siliceous matter to the stems of the grasses and other plants—and that rising, as it naturally does, to the surface of the soil, it there, in the presence of vegetable matter, provokes to the formation of nitrates, so wholesome to vegetable life—we may regard the decomposing action of lime by which this carbonate is produced as among the most valuable of its properties to the practical farmer, wherever circumstances are favourable for its exercise.

§ 33. *Action of lime on animal and vegetable life.*

It is only necessary to allude, in conclusion, to one or two other useful purposes which lime is said to serve in reference to animal and vegetable life. Thus

1°. It is said to prove fatal, especially in the caustic state, to worms, to slugs,[*] and to many insects injurious to the farmer, and to destroy their eggs and larvæ. In Scotland it has been found in some instances to check the ravages of the fly. On the other hand, in the state of carbonate, it is propitious to the growth of the land snail and similar creatures which bear shells. In highly limed land the former may be seen crowded at the roots of the hedges, from which they make frequent incursions upon the young crops, and are, I believe, especially hurtful to the turnips.

2°. It is found to prevent *smut* in wheat. For this purpose the seed is steeped in lime, and afterwards dried with slaked lime, or lime water is poured upon the heap of corn, which is turned over, and left for 24 hours (Hillyard.)

3°. It is also said to prevent the rot and foot-rot in sheep fed upon pastures on which, before liming, the stock was liable to be affected by these diseases (Prideaux.)

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[*] When the wheat crop is attacked by slugs above ground, nothing will do so much good as slaked lime, sown over the crop before sunrise.—Hillyard, *Royal Agricultural Journal*, iii., p. 302.

4°. In regard to its action upon living plants, it is certain that it extirpates certain of the coarser grasses from sour pastures and brings up a tenderer herbage; but practical men appear to differ in regard to its effects upon the roots and seeds of the more troublesome weeds. According to some, the addition of lime to a compost, or to the soil, will kill the roots of weeds and render unproductive such noxious seeds as may happen to be present. According to others (Part III., p. 157,) this is a mistake. I believe the truth to be, that lime will lead to their destruction and decay, if the circumstances are favorable or if proper pains be taken to effect it. But air and moisture are necessary to insure this, as they are to effect the rapid decay of dead organic matter. If the ingredients of the compost be duly proportioned, or if the dose of lime added to the land be sufficiently large, and if in each case the mixture be frequently turned, the final destruction of roots and seeds may in general be safely calculated upon.

§ 34. *Use of silicate of lime.*

There is one compound of lime which, though occurring occasionally in all soils, has not hitherto been applied to the improvement of the land even in localities where it most abounds. This compound is the *silicate* of lime. I have already directed your attention to the presence of this compound in the trap rocks, and to the fertile character which it imparts to the soils which are formed by the natural degradation of these rocks.

In those districts where the smelting of iron is carried on, the first slag that is obtained consists in great part of silicate of lime. This slag accumulates in large quantities, and is employed in some districts for mending the roads. It is not unworthy the attention of the practical farmer—as an improver of his fields—especially where caustic lime is distant and expensive, or where boggy and peaty soils are met with in which vegetable matter abounds. On such land it may be laid in large quantity. It will decompose slowly, and while it imparts to the soil solidity and firmness, will supply both lime and silica to the growing crops, for a long period of time.

I have thus drawn your attention to the most important topics connected with the use of lime, so efficacious an instrument in the hands of the skilful and improving farmer for ameliorating the condition and increasing the productiveness of his land. If I have appeared to dwell long upon this subject, it is because of the value which I know to be attached by practical men to a correct exposition of the virtues of lime and of the theory by which its effects are to be explained. I believe that in the theoretical part I have been able to point out to you the leading chemical principles upon which its influence depends—if any thing is still dark, it is because our knowledge is not yet complete. A few years more, and we may hope to have the mists which hang over this as over many other branches of agricultural chemistry in a great measure cleared away.

LECTURE XVIII.

Of organic manures. Vegetable and animal manures. Green manuring—ploughing in of spurry, the white lupin, the vetch, buckwheat, rape, rye, borage. Natural green manuring. Improvement of the soil by laying down to grass and by planting. Use of seaweed. Dry vegetable manures—dry straw, chaff, rape-dust, malt-dust, saw-dust, cotton seeds, dry leaves. Decayed vegetable matter—use of peat, tanners' bark, and composts of vegetable matter. Charcoal powder, soot. Relative value—theoretical and practical—of different vegetable manures.

By *organic* manures are understood all those substances either of vegetable or of animal origin, which are applied to the land for the purpose of increasing its fertility. It will be convenient to consider these two classes of organic substances separately.

The parts of vegetables may be applied to the soil in three different forms—in the green, in the dry, and in the more or less naturally decayed, fermented, or artificially decomposed state.

§ 1. *Of green manuring, or the application of vegetable matter in the green state.*

By green manuring is meant the ploughing in of green crops in their living state—or of green vegetables left or spread upon the land for the purpose.

1°. We have seen in the preceding lecture how important air and water are to the decomposition of organic matter. Now green vegetable substances contain within themselves much water, undergo decomposition more readily, therefore, than such as have been dried, and are more immediately serviceable when mixed with the soil.

2°. In the sap of plants also there generally exist certain compounds containing nitrogen, which not only decompose very readily themselves, but have the property of persuading or inducing the elements of the other organic matters, with which they are in contact, to assume new forms or to enter new chemical combinations. Hence, the sap of plants almost invariably undergoes more or less rapid decomposition even when preserved from the contact of both air and water. When this decomposition has once commenced in the sap it is gradually propagated to the woody fibre and to the other substances of which the mass of the stems and roots of plants is composed. Hence, recent vegetable matter will undergo a comparatively rapid decomposition, even when buried to some depth beneath the soil—and the elements of which it consists will form new compounds more or less useful to living plants, in circumstances where dry and where many forms even of partially decomposed vegetable matter would undergo no change whatever.

3°. Further—when green vegetable matter is allowed to decay in the open air, it is gradually resolved more or less completely into carbonic acid, which escapes into the air and is so far lost. But when buried beneath the surface, this formation of carbonic acid proceeds less rapidly, and other compounds—preparatory to the final resolution into carbonic acid and water—are produced in greater quantity and linger in the soil. Thus by burying vegetable substances in his land in their green state, the practical man actually saves a portion of the organic food of plants, which would otherwise so far run to waste.

4°. Finally. Green vegetable substances, by exposure to the air, gradually give up a portion of the saline matter they contain to the showers of rain that fall. This more or less escapes and is lost. But if buried beneath the soil this saline matter is restored to the land, and where the green matter thus buried is in the state of a growing crop, both the organic and inorganic substances it contains are more equally diffused through the soil than they could be by any other known process.

On one or other of these principles depend nearly all the *special* advantages which are known to follow from green manuring and from the employment of green vegetable matter in the preparation of composts.

§ 2. *Important practical results obtained by green manuring.*

But this explanation of the principles on which the efficacy of *green* manuring depends, does not fully illustrate the important practical results by which, in many localities, it is uniformly followed.

Let us glance at these results.

1°. The ploughing in of green vegetables on the spot where they have grown may be followed as a method of manuring and enriching *all* land—where other manures are less abundant. Growing plants bring up from beneath, as far as their roots extend, those substances which are useful to vegetation—and retain them in their leaves and stems. By ploughing in the whole plant we restore to the surface what had previously sunk to a greater or less depth, and thus make it more fertile than before the green crop was sown.

2°. This manuring is performed with the least loss by the use of vegetables in the green state. By allowing them to decay in the open air, there is, as above stated, a loss both of organic and of inorganic matter—if they be converted into fermented (farm-yard) manure, there is also a large loss, as we shall hereafter see, and the same is the case, if they are employed in feeding stock, with a view to their conversion into manure. *In no other form can the same crop convey to the soil an equal amount of enriching matter as in that of green leaves and stems.* Where the *first* object, therefore, in the farmer's practice is, so to use his crops as to enrich his land—he will soonest effect it by ploughing them in in the green state.

3°. Another important result is, that the beneficial action is almost immediate. Green vegetables decompose rapidy, and thus the first crop which follows a green manuring is benefitted and increased by it. But partly for this reason also the green manuring—of corn cropped land—if aided by no other manure, must generally be repeated every second year.

4°. It is said that grain crops which succeed a green manuring are never laid—and that the produce in grain is greater in proportion to the straw, than when manured with fermented dung.

5°. But it is deserving of separate consideration, that green manuring is especially adapted for improving and enriching soils which are poor in vegetable matter. The principles on which living plants draw a part—sometimes a large part—of their sustenance from the air have already been discussed, and I may presume that you sufficiently understand the principles and admit the fact. Living plants, then, contain in their substance not only all they have drawn up from the soil, but also a great part of what they have drawn down from the air. Plough in these living plants, and you necessarily add to the soil more than was taken from it—in other words, you make it richer in *organic* matter. Repeat the process with a second crop and it becomes richer still—and it would be difficult to define the limit beyond which the process could no further be carried.

Is there any soil then, in the ordinary climates of Europe, which is beyond the reach of this improving process? Those only are so on which plants refuse to grow at all, or on which they grow so languidly as to extract from the air no more than is restored to it again by the natural decay of the organic matter which the soils already contain.

But for those plants which grow naturally upon the soil, agricultural skill may substitute others, which will increase more rapidly, and produce a larger quantity of green leaves and stems for the purpose of being buried in the soil. Hence, the selection of particular crops for the purpose of given manuring—those being obviously the fittest which in the given soil and climate *grow most rapidly, or which produce the largest quantity of vegetable matter in the shortest time and at the smallest cost.*

§ 3. *Of the plants which in different soils and climates are employed for green manuring.*

On this principle is founded the selection of *different* plants in different soils and climates for the purpose of green manuring. That which in Italy will yield the largest produce of leaves and stems, at the least cost, and in the shortest time, may not do so in the north of England or of Germany—and that which will enrich a poor clay or an exhausted loam may refuse even to grow, in a healthy manner, upon a drifting sand.

1°. *Spurry* (Spergula Arvensis).—It is to poor dry sandy soils that green manuring has been found most signally beneficial, and for such soils no plant has been more lauded than *spurry*. It may either be sown in autumn on the corn stubble or after early potatoes, and ploughed in in spring preparatory to the annual crop, or it may be used to replace the naked fallow, which is often hurtful to lands of so light a character. In the latter case, the first sowing may take place in March, the second in May, and the third in July—each crop being ploughed in to the depth of three or four inches, and the new seed then sown and harrowed. When the third crop is ploughed in, the land is ready for a crop of winter corn.

Von Voght* states that by such treatment the worst shifting sands may be made to yield remunerative crops of rye—that the most worthless sands are more improved by it than those of a better natural quality—that the green manuring every other year not only nourishes sufficiently the alternate crops of rye, but gradually enriches the soil—and that it increases the effect of any other manure that may subsequently be put on. He adds, also, that spurry produces often as much improvement if eaten off by cattle as if ploughed in, and that when fed upon this plant, either green or in the state of hay, cows not only give more milk, but of a richer quality.

2°. *White Lupins.*—In Italy, and in the south of France, the white lupin is extensively cultivated as a green manure. In Germany, also, it has been found to be one of those plants by which unfruitful sandy soils may be most speedily brought into a productive state. The superiority of this plant for the purpose of enriching the soil depends upon its deep roots, which descend more than two feet beneath the surface—upon its being little injured by drought, and little liable to be attacked by insects—on its rapid growth—and upon its large produce in leaves and stems. Even in the North of Germany it is said to yield, in three and a-half to four months, 10 to 12 tons of green herbage. It grows in all soils except such as are marly and calcareous, is especially partial to such as have a ferruginous subsoil, and besides enriching, also *opens* stiff clays by its strong stems and roots.

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* *Vortheile der grünen Bedüngung.*

3°. *The Vetch* is inferior in many of its qualities to the white lupin—yet in Southern Germany it is often sown on the stubble, and ploughed in after it has been touched with the frost, and has begun to decay. In England also the winter tare ploughed in early in spring has been found highly advantageous.* It is a more precarious, however, and a more expensive crop than either of the former, and requires a better soil for its successful growth.

4°. *Buck-Wheat* is also too uncertain a crop, and the high price of its seed renders it inferior in value to spurry on sandy soils. It is superior to this latter plant, however, on poor heaths. In Southern Germany it is sown on the stubble and ploughed in when it is 18 or 20 inches high.

5°. *Rape* can only be sown upon a soil which is already in some measure rich, but it has the advantage of continuing to grow very late in the autumn, and of beginning again very early in spring. It sends down deep roots also, and loosens clayey soils by its thick stems. In the light soils of Alsace it is sown after early peas and potatoes, and manures the land for the succeeding crop of wheat or rye.

5°. *Rye* is pronounced by Von Voght to be the best of all green manures for sandy soils, but it is also the most expensive. It is a very sure crop and begins to grow very early in the spring, but it is not deep rooted. It has been used with advantage in Northern Italy and in Germany.

6°. *Turnips* have been sown in Sussex with good effect as a stubble crop for ploughing in in spring, and in Norfolk and elsewhere the portions of the turnip bulbs which are left when they are eaten off by sheep contribute, when ploughed in, to enrich the land for the barley that is to follow. Turnip tops are in many places ploughed in with much benefit to the land.† Potato tops also might be dug or ploughed in with equal advantage.

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* *British Husbandry*, I., p. 407.

† "I find no better way of manuring for wheat after turnips, than ploughing in the tops while still *green*, as soon as the turnips are taken off the land."—*Mr. Campbell, of Craigie.*

7°. *Borage* has been strongly recommended in Germany, and especially by Lampadius. It is stated by this experimenter that borage draws from the air ten times as much of the elements of its organic matter as it does from the soil, and that therefore it is admirably fitted for enriching the land on which it grows.

8°. *Red Clover* is often ploughed in as a manure. On the Rhine it is sown for this purpose, being ploughed in before it begins to flower. In French Flanders two crops of clover are cut, and the third ploughed in, and in some parts of the United States of North America the clover which alternates with the wheat crop is ploughed in as the only manure.* White Clover is not so valuable for this purpose, for neither is it so deep rooted nor does it yield so large a crop of stems and leaves.

9°. *Old grass.*—Perhaps the most common form of green manuring practised in this country is that of ploughing up grass lands of various ages. The green matter of the sods serves to manure the after-crop, and renders the soil capable of yielding a richer return at a smaller expense of manure artificially added.

In regard to all these forms of green manuring it is to be observed that they enrich the soil generally, and are therefore well fitted to prepare it for after-crops of corn; they will not fit it, however, for a special crop, such as turnips, which requires to be unnaturally forced or pushed forward at a particular period of its growth.

§ 4. *Will green manuring alone prevent land from becoming exhausted?*

If by green manuring is meant the growing of vegetable matter upon one field, and ploughing it in green into another, as is sometimes done, it may be safely said that, when judiciously practised, land may by this single process be secured for an indefinite period against exhaustion. But if we plough in only what the land itself produces, and carry off occasional crops of corn, the time will ultimately come when any soil thus treated will cease to yield remunerating crops. A brief consideration of the subject will satisfy you of this.

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* Barclay's *Agricultural Tour in the United States.*

Suppose a loose sand to be improved by repeatedly sowing and ploughing in crops of spurry or white lupins, the green leaves and stems fix the floating elements of the atmosphere, and enrich the soil with organic matter, while the roots, more or less deep, bring up saline matters to the surface, and thus supply to the plant what is no less necessary to its healthy growth. But the rains yearly wash away from the surface, and the corn crops remove a portion of this saline matter. This portion the crops grown for the purpose of green manuring yearly renew by fresh supplies from beneath. But no subsoil contains an inexhaustible store of those saline substances which plants require. Hence, though by skilful green manuring waste land may be brought to a remunerative state of fertility, it will finally relapse again into a state of nature, if no other methods are subsequently adopted for maintaining its productiveness. The process may be a slow one, and practical men may be unwilling to believe in the possibility of a result which does not exhibit itself within the currency of a single lease, or during a single life-time—yet few things are more certain than that *in general* the soil must sooner or later receive supplies of *saline* manure in one form or another, or else must ultimately become unproductive. It may be considered as a proof of this fact that, in all densely peopled countries in which agriculture has been skilfully prosecuted, the manufacturing of such manures has become an important branch of business, giving employment to many hands, and affording an investment to much capital.

The following Table, in addition to other particulars, exhibits the relative proportions of *dry* organic and saline matter, capable of being added to the surface soil by a few of those plants which are employed for the purposes of green manuring :—

Kind of Plant.	Average produce per imp. Acre.	1000 lbs. contain in the green state,		Depth of Roots.	Crops in a Year.	Soil for which they are fitted.
		Organic Matter.	Saline Matter.			
	lbs.	lbs.	lbs.	inches.		
Spurry - -	6,500	199	21	12 to 15	2 or 3	Dry, loose, sandy.
WhiteLupin	25,000	188	12	24 to 26	1 or 1½	Any except marly or calcareous.
Vetch - -	11,000	233	17	15 to 20	2	Strong soil.
Buck-wheat	8,000	170	10	12 to 15	2	Dry, sandy, or moorish.
Rape - - -	16,000	214	16	?	1 or 1½	Rich soil.

§ 5. *Of the practice of green manuring.*

In the practical adoption of green manuring it is of importance to bear in mind—

1°. That a sufficient quantity of seed must be sown to keep the ground well covered, one of the attendant advantages of stubble crops being that they keep the land clean and prevent it from becoming a prey to weeds.

2°. That the plants ought to be mown or harrowed, and at once ploughed in *before they come into full flower*. The flower-leaves give off nitrogen into the air, and as this element is supposed especially to promote the growth of plants, it is desirable to retain as much of it in the plant and soil as possible. Another reason is that, if allowed to ripen, some of the seed may be shed and afterwards infest the land with weeds.

3°. That they should be ploughed in to the depth of 3 or 4 inches only, that they may be covered sufficiently to prevent waste, and yet be within reach of the air, and of the early roots of the succeeding crop.

§ 6. *Of natural manuring with recent vegetable matter.*

Besides the method of ploughing in, which may be distinguished as *artificial* green manuring,—there is another mode in which recent vegetable matter is employed in nature for the purpose of enriching the soil. The natural grasses grow and die upon a meadow or pasture field, and though that which is above the surface may be mowed for hay, or cropped by cattle, yet the roots remain and gradually add to the quantity of vegetable matter beneath. The same is the case to a greater or less extent with all the artificial corn, grass, and leguminous crops we grow. They all leave their roots in the soil, and if the quantity of organic matter which these roots contain be greater than that which the crop we carry off has derived from the soil, then instead of exhausting, the growth of this crop will actually enrich the soil in so far as the presence of organic matter is concerned. No crops, perhaps, *the whole produce of which is carried off the field*, leave a sufficient mass of roots behind them to effect this end, but many plants, when in whole or in part eaten upon the field, leave enough in the soil materially to improve the condition of the land—while in all cases those are considered as the least exhausting, to which are naturally attached the largest weight of roots. Hence, the main reason why poor lands are so much benefitted by being laid down to grass, and why an intermediate crop of clover is often as beneficial to the after crop of corn as if the land had lain in naked fallow.*

An interesting series of experiments on the relative weights of the roots and of the green leaves and stems of various grasses, made by Hlubek,† throws considerable light upon their relative efficacy in enriching the soil by the vegetable matter they diffuse through it in the form of roots. The grasses were grown in beds of equal size (180 square feet), in the agricultural garden at Laybach, and mown on the fourth year after sowing, just as they were coming into flower. The roots were then carefully taken up, washed, and dried. The results were as follow:—

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* If the third crop be ploughed in, the land is actually enriched.—*Schwertz.*

† *Ernährung der Pflanzen*, p. 466.

Kind of Grass.	Produce in		Produce in Roots.		Weight of dry Roots to 100 lbs. of Hay.
	Grass.	Hay.	Fresh.	Dry.	
	lbs.	lbs.	lbs.	lbs.	lbs.
1. Festuca Elatior—*Tall Fescue-grass* -	124	36	56	22	61
2. Festuca Ovina—*Sheep's Fescue-grass* -	90	30	—	80	266
3. Phleum Pratense—*Timothy grass* - -	90	25	56	17	60
4. Dactylis Glomerata—*Rough Cock's-foot* -	202	67	—	22½	33
5. Lolium Perenne—*Perennial Rye-grass* -	50	17	—	50	300
6. Alopecurus Pratensis—*Meadow Fox-tail* -	106	35	—	24	70
7. Triticum Repens—*Creeping Couch or Quicken-grass*	120	60	—	70	116
8. Pon Annua—*Annual Meadow-grass* -	—	—	—	—	111
9. Bromus Mollis and Racemosus—*Soft and smooth Brome-grass*	—	—	—	—	105
10. Anthoxanthum Odoratum—*Sweet-scented Vernal-grass* - -	—	—	—	—	93

A mixture of white clover, of ribwort, of hoary plantain, and of couch-grass, in an old pasture field, gave 400 lbs. of dry roots to 100 lbs. of hay—and in a clover field, at the end of the second year, the fresh roots were equal to one-third of the whole weight of green clover obtained at three cuttings—one in the first, and two in the second year—while in the dry state there were 56 lbs. of dry roots to every 100 lbs. of clover hay which had been carried off.

The fourth column of the above table shows how large a quantity of vegetable matter some of the grasses impart to the soil, and yet how unlike the different grasses are in this respect. The sheep's-fescue and the perennial rye-grass—besides the dead roots, which detach themselves from time to time—leave, at the end of the fourth year, a weight of *living* roots in the soil which is equal to three times the produce of that year in hay. If we take the mean of all the above grasses as an average of what we may fairly expect in a grass field—then *the amount of living roots left in the soil when a four-year-old grass field is ploughed up, will be equal to one-sixth more than the weight of that year's crop.*

In an old pasture or meadow field again, when ploughed up, *the living roots left are equal to four times the weight of that year's hay crop.* If a ton and a half of hay have been reaped—then about six tons of dry vegetable matter remain in the soil in the form of roots.

In the case of clover, at the end of the second year the quantity of dry vegetable matter left in the form of roots is equal to upwards of one-half the weight of the whole hay which the clover has yielded. Suppose there be three cuttings, yielding 4 tons of hay, then 2 *tons of dry vegetable matter are added to the soil in the form of roots, when the clover stubble is ploughed up.*

But the quantity of roots, like that of green produce, is dependant upon a variety of circumstances. It will sometimes, therefore, be greater and sometimes less than is above stated. It may be received as a rule—not without exceptions perhaps, yet still as a general rule—that whatever causes an increased produce above ground, will cause a corresponding increase in the growth of roots. Thus nitrate of soda, which gives us a larger yield of hay, makes the roots also stronger and deeper, and the sward tougher and more difficult to plough (see *Appendix.*) Hence it is that the farmer is anxious that his clover crop should succeed, not merely for the increased amount of green food or of hay it will give him, but because it will secure him also a better after crop of corn.

This burying of recent vegetable matter in the soil, in the form of living and dead roots of plants, is one of those important ameliorating operations of nature, which is always to some extent going on, wherever vegetation proceeds. It is one by which the practical man is often benefitted unawares, and of which—too often without understanding the source from whence the advantage comes—he systematically avails himself in some of the most skilful steps he takes with a view to the improvement of his land.

§ 7. *Improvement of the soil by laying down to grass.*

One of the most common of these methods of improvement is that of *laying down to grass.* This may be done for two, three, or four years only, or for an indefinite period of time. In the latter case, the land is said to be laid down permanently, or to permanent pasture.

1°. *Temporary pasture or meadow.*—If the land be sown with grass and clover-seeds, only as an alternate crop between two sowings of corn, the effect is fully explained by what has been already stated (§ 6.) The roots which are left in the soil enrich the surface with both organic and inorganic matter, and thus fit it for bearing a better after crop of corn.

If, again, it be left to grass for three or five years, the same effect is produced more fully, and therefore this longer rest from corn is better fitted for soils which are poor in vegetable matter. The quantity of organic matter which has accumulated becomes greater every year, in consequence of the annual death of stems and roots, and of the soil being more closely covered, but this increase is probably never in any *one* after-year equal to that which takes place during the first. The quantity of roots which is produced during the first year of the young plants' growth must, we may reasonably suppose, be greater than can ever afterwards be necessary in an equal space of time. Hence, one good year of grass or clover will enrich the soil more *in proportion to the time expended,* than a rest of two or three years in grass, *if annually mowed.*

Or, if instead of being mown, the produce in each case be eaten off by stock, the result will be the same. That which lies longest will be the richest when broken up, but not in an equal proportion to the time it has lain. The produce of green parts, as well as of roots, in the artificial grasses, is generally greatest during the first year after they are sown, and therefore the manuring derived from the droppings of the stock, as well as from the roots, will be greatest in proportion during the first year. That farming, therefore, is most economical—where the land will admit of it—which permits the clover or grass seeds to occupy the land for one year only.

But if, after the first year's hay is removed, the land be pastured for two or three years more, it is possible that each succeeding year may enrich the surface soil as much as the roots and stubble of the first year's hay had done; so that if it lay three years it might obtain three times the amount of improvement. This is owing to the circumstance that the whole produce of the field remains upon it, except what is carried off by the stock when removed—but very much, it is obvious, will depend upon the nature of the soil and upon the selection of the seeds being such, as to secure a tolerable produce of green food during the second and third years.

2°. *Permanent pasture or meadow.*—But when land is laid down to permanent grass it undergoes a series of further changes, which have frequently arrested attention, and which, though not difficult to be understood, have often appeared mysterious and perplexing to practical men. Let us consider these changes.

a. When grass seeds are sown for the purpose of forming a permanent sward, a rich crop of grass is obtained during the first, and perhaps also the second year, but the produce after three or four years lessens, and the value of the pasture diminishes. The plants gradually die and leave blank spaces, and these again are slowly filled up by the sprouting of seeds of other species, which have either lain long buried in the soil or have been brought thither by the winds.

This first change, which is almost universally observed in fields of artificial grass, arises in part from the change which the soil itself has undergone during the few years that have elapsed since the grass seeds were sown, and in part from the species of grass selected not being such as the soil, at any time, could permanently sustain.

b. When this deterioration, arising from the dying out of the sown grasses, has reached its utmost point, the sward begins gradually to improve, natural grasses suited to the soil spring up in the blank places, and from year to year the produce becomes greater and greater, and the land yields a more valuable pasture. Practical men often say that to this improvement there are no bounds, and that the older the pasture the more valuable it becomes.

But this is true only within certain limits. It may prove true for the entire currency of a lease, or even for the life-time of a single observer, but it is not generally true. Even if pastured by stock only and never mown—the improvement will at length reach its limit or highest point, and from this time the value of the sward will begin to diminish.

c. This, again, is owing to a new change which has come over the soil. It has become, in some degree, exhausted of those substances which are necessary to the growth of the more valuable grasses—less nutritive species, therefore, and such as are less willingly eaten by cattle, take their place.

Such is the almost universal process of change which old grass fields undergo, whether they be regularly mown or constantly pastured only—provided they are left entirely to themselves. If mown they begin to fail the sooner, but even when pastured they can be kept in a state of full productiveness only by repeated top-dressings, especially of saline manure—that is, by adding to the soil those substances which are necessary to the growth of the valuable grasses, and of which it suffers a yearly and unavoidable loss. Hence the rich grass lands of our fathers are found now in too many cases to yield a herbage of little value. Hence, also, in nearly all countries, one of the first steps of an improving agriculture is to plough out the old and failing pastures, and either to convert them permanently into arable fields, or, after a few years' cropping and manuring, again to lay them down to grass.

But when thus ploughed out, the surface soil upon old grass land is found to have undergone a remarkable alteration. When sown with grass seeds, it may have been a stiff, more or less grey, blue, or yellow clay—when ploughed out it is a rich, brown, generally light and friable vegetable mould. Or when laid down it may have been a pale-coloured, red, or yellow sand or loam. In this case the surface soil is still, when turned up, of a rich brown colour—it is lighter only and more sandy than in the former case, and rests upon a subsoil of sand or loam instead of one of clay. It is from the production of this change that the improvement caused by laying land down to grass principally results. In what does this change consist? and how is it effected?

If the surface soil upon stiff clay lands, which have lain long in grass, be chemically examined, it will be found to be not only much richer in organic matter, but often also poorer in alumina than the soil which formed the surface when the grass seeds were first sown upon it. The brown mould which forms on lighter lands will exhibit similar differences when compared with the soil on which it rests; but the proportion of alumina in the latter being originally small, the difference in respect to this constituent will not be so perceptible.

The effect of this change on the surface soil is in all cases to make it more rich in those substances which cultivated plants require, and therefore more fertile in corn. But strong clay lands derive the further important benefit of being rendered more loose and friable, and thus more easily and more economically cultivated.

The mode in which this change is brought about is as follows:—

1°. The roots, in penetrating, open and loosen the subjacent stiff clay. Diffusing themselves every where, they gradually raise, by increasing the bulk, of the surface soil. The latter is thus converted into a mixture of clay and decayed roots, which is of a dark colour, and is necessarily more loose and friable than the original or subjacent unmixed clay.

2°. But this admixture of roots affects the chemical composition as well as the state of aggregation of the soil. The roots and stems of the grasses contain much inorganic—earthy and saline—matter (Part II., p. 261), which is gathered from beneath, wherever the roots penetrate, and is by them sent upwards to the surface. A ton of hay contains about 170 lbs. of this inorganic matter (Part II., p. 323). Suppose the roots to contain as much, and that the total annual produce of grass and roots together amounts to four tons, then about 680 lbs. of saline and earthy matters are every year worked up by the living plants, and in a great measure permanently mixed with the surface soil. Some of this, no doubt, is carried off by the cattle that feed, and by the rains that fall, upon the land—some remains in the deeper roots, and some is again, year after year, employed in feeding the new growth of grass—still a sufficient quantity is every season brought up from beneath, gradually to enrich the surface with valuable inorganic matter at the expense of the soil below.

3°. Nor are mechanical agencies wanting to increase this natural difference between the surface and the under soils. The loosening and opening of the clay lands by the roots of the grasses allow the rains more easy access. These rains gradually wash out the fine particles of clay that are mixed with the roots, and carry them downwards, as they sink towards the subsoil. Hence the brown mould, as it forms, is slowly robbed of a portion of its alumina, and is rendered more open, while the under soil becomes even stiffer than before. This sinking of the alumina is in a great measure arrested when the soil becomes covered with so thick a sward of grass as to break the force of the rain-drops or of the streams of water by which the land is periodically visited. Hence the soil of some rich pastures contains as much as 10 or 12, of others as little as 2 or 3 per cent. of alumina.

4°. The winds also here lend their aid. From the naked arable lands, when the weather is dry, every blast of wind carries off a portion of the dust. This it suffers to fall again as it sweeps along the surface of the grass fields—the thick sward arresting the particles and sifting the air as it passes through them. Every where, even to remote districts, and to great elevations, the winds bear a constant *small* burden of earthy matter;* but there are few practical agriculturists who, during our high winds, have not occasionally seen the soil carried off in large quantities from their naked fields. Upon the neighbouring grass lands this soil falls as a natural top-dressing, by which the texture of the surface is gradually changed and its chemical constitution altered.

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* It has been observed that on spots purposely sheltered from the wind and rain on every side, the quantity of dust that is collected, when *pressed*

5°. Another important agency also must not be overlooked. In grass lands insects, and especially earth-worms abound. These almost nightly ascend to the surface, and throw out portions of finely-divided earthy matter. On a close shaven lawn the quantity thus spread over the surface in a single night often appears surprising. In the lapse of years the accumulation of the soil from this cause must, on old pasture fields, be very great. It has often attracted the attention of practical men,* and so striking has it appeared to some, that they have been inclined to attribute to the slow but constant labour of these insects, the entire formation of the fertile surface soils over large tracts of country.†

I have directed your attention to these causes chiefly in explanation of the changes which by long lying in grass the surface of our stiff clay lands is found to undergo. But they apply equally to other soils also—the only difference being that, in the case of such as are already light and open, the change of texture is not so great, and therefore does not so generally arrest the attention.

Upon this subject I may trouble you further with two practical remarks—

1°. That the richest old grass lands—those which have remained longest in a fertile condition—are generally upon our strongest clay soils (the Oxford and Lias clays, Part II., pp. 360 and 362). This is owing to the fact that such soils naturally contain, and by their comparative impermeability *re*-tain, a larger store of those inorganic sub-

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down, is in 3 years equal to one line, or *in 36 years to one inch in thickness.*—Sprengel, *Lehre vom Dünger*, p. 443.

* The permanence of a fine carpeting of rich and sweet grass upon a portion of his farm is ascribed (by Mr. Purdie) to "the spewings of the worms, apparently immensely numerous, which incessantly act as a rich top-dressing."—*Prize Essays of the Highland Society*, I., p. 191.

† *Geological Transactions.*

stances on which the valuable grasses live. When the surface soil becomes deficient in any of these, the roots descend further into the subsoil and bring up a fresh supply. But these grass lands are not on this account exempt from the law above explained, in obedience to which all pastured lands, when left to nature, must ultimately become exhausted. They must eventually become poorer; but in their case the deterioration will be slower and more distant, and by judicious top-dressings may be still longer protracted.

2°. The natural changes which the surface soil undergoes, and especially upon clay lands when laid down to grass, explain why it is so difficult to procure, by means of artificial grasses, a sward equal to that which grows naturally upon old pasture lands. As the soil changes upon our artificial pastures, it becomes better fitted to nourish other species of grass than those which we have sown. These naturally spring up, therefore, and cover the soil. But these intruders are themselves not destined to be permanent possessors of the land. The soil undergoes a further change, and new species again appear upon it. We cannot tell how often different kinds of grass thus succeed each other upon the soil, but we know that the final rich sward which covers a grass field when it has reached its most valuable condition, is the result of a long series of natural changes which time only can bring about.

The soil of an old pasture field, which has been ploughed up, is made to undergo an important change both in texture and in chemical constitution, before it is again laid down to grass. The same grasses, therefore, which previously covered it will no longer flourish, even when they are sown. Hence the unwillingness felt by practical men to plough up their old pastures—but hence, also, the benefit which results from the breaking up of such as are old, worn out, or covered with unwholesome grasses. When again converted into pasture land, new races appear, and a more nourishing sward is produced.*

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* For an excellent article on the superior feeding qualities of recent artificial grasses over many old pasture lands by Mr. Boswell, of Kingcaussie. —See the *Quarterly Journal of Agriculture*, N., p. 783.

§ 8. *Improvement of the soil by the planting of trees.*

It has long been observed by practical men, that when poor, thin, unproductive soils have been for some time covered with wood, their quality materially improves. In the intervals of the open forest, they will produce a valuable herbage—or when cleared of trees they may for some time be made to yield profitable crops of corn.

This fact has been observed in almost every country of Europe, but the most precise observations upon the subject with which I am acquainted are those which have been made in the extensive plantations of the late Duke of Athol. These plantations consist chiefly of white larch, (*Larix Europæa*) and grow upon a poor hilly soil, resting on gneiss, mica-slate, and clay-slate (Part II., pp. 371, 372). In six or seven years the lower branches spread out, become interlaced, and completely overshadow the ground. Nothing, therefore, grows upon it till the trees are 24 years old, when the spines of the lower branches, beginning to fall, the first considerable thinning takes place. Air and light being thus re-admitted, grasses (chiefly *holcus mollis* and *lanatus*) spring up, and a fine sward is gradually produced. The ground, which previously was worth only 9d. or 1s. per acre as a sheep pasture, at the end of 30 years becomes worth from 7s. to 10s. per acre.

The soil on this part of the Duke's estate is especially propitious to the larch—and, therefore, this tree both thrives best and in the greatest degree improves the soil. Thus in oak copses, cut every 24 years, the soil becomes worth only 5s. or 6s. per acre, and this during the last six years only. Under an ash plantation, the improvement amounts to 2s. or 3s. per acre; under Scotch fir, it does not exceed 6d. an acre—while under spruce and beech the land is worth less than before.*

The main cause of this improvement, as of that which is produced by laying down to grass, is to be found in the natural manuring with recent vegetable matter, to which the soil year by year is so long subjected. Trees differ from grasses only in this, that while the latter enrich the soil both by their roots and by their leaves, the former manure its surface only by the leaves which they shed.

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* Mr. Stephens in the *Transactions of the Highland Society*, xi., p. 189; also Loudon's *Encyclopædia of Agriculture*, p. 1346.

The leaves of trees, like those of the grasses, contain much inorganic matter, and this when annually spread upon the ground slowly adds to the depth as well as to the richness of the soil. Thus the leaves of the following trees, when dried in the air, contain respectively of inorganic matter* :—

	APRIL. per cent.	AUGUST. per cent.	NOVEMBER. per cent.
Oak	—	5	4½
Ash	—	6¼	—
Beech	—	7	—
Birch	—	4	—
Elm	—	11¾	—
Willow	—	8¼	—
White Larch	6 J.	—	—
Scotch Fir	—	1¾	—

In looking at the differences among these numbers—especially in the case of the elm and of the Scotch fir—one would naturally suppose that the diversity of their effects in improving the land is in some measure to be ascribed to the quantity and kind of the inorganic matter which the leaves of these several trees contain. And to this cause, no doubt, some effect is to be ascribed in localities *where all the trees thrive equally*.

But upon the quantity of leaves produced, as much in general will depend, as upon the relative proportions of organic and inorganic matter which these leaves may respectively contain. And as the quantity of leaves is always greatest where the tree flourishes best or finds a most propitious soil—the improvement of the soil itself, by any particular tree, will be always in a great measure determined by its fitness to promote the growth of that kind of tree.

On the soil planted by the Duke of Athol, the larch shot up luxuriantly, while the Scotch fir lingered and languished in its growth. Thus the quantity of leaves produced and annually shed by the former was vastly greater than by the latter tree. Had the Scotch fir thriven better than the larch, the reverse might have been the case, and the value of the soil might have been increased in a greater proportion by plantations of the former tree.

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* Sprengel, *Chemie fur Landwirthe*, ii., passim.

Other special circumstances also will account for the relative degrees of improvement produced by the larch and by some of the other trees—for example, the oak. In the oak copse the soil in 16 years became worth 6s. or 8s. an acre. If, therefore, instead of being cut down for their bark at the end of 24 years, the trees had been allowed to grow up into an oak forest, the permanent improvement of the pasture, even on this soil, would probably have been at least as great as under the larch. The above experiments, therefore, are in reality not so decisive in regard to the relative *improving power* of the several species of trees as they at first sight appear. The most rational natural rule by which our practice should be guided seems to be contained in these three propositions—

1°. That the soil will be most improved by those trees which thrive best upon it.

2°. Among those which thrive equally, by such as yield the largest produce of leaves, and—

3°. Among such as yield an equal weight of leaves, by those whose leaves contain the largest proportion of inorganic matter—which bring up from beneath, that is, and spread over the surface in largest quantity, the materials of a fertile soil.

The mode in which the lower branches of the larch spread out and overshadow the surface is not without its influence upon the ultimate improvement which the soil exhibits. All vegetation being prevented, the land, besides receiving a yearly manure of vegetable mould, is made to lie for upwards of 20 years in uninterrupted naked fallow. It is sheltered also from the beating of the rain drops, which descend slowly and gently upon it, bearing principles of fertility instead of washing out the valuable saline substances it may contain.

Beneath the overshadowing branches of a forest, the soil is also protected from the wind, and to this protection Sprengel attributes much of that rapid improvement so generally experienced where lands are covered with wood. The winds bear along particles of earthy matter* which they deposit again in the still forests; and thus gradually form a soil even on the most naked places. This slow general cause of accumulation may not be without its effect, and should not be forgotten, but it evidently affords no explanation why, in the same range of country, the soil which is covered by forests of one kind should improve more rapidly, than those which are sheltered by trees of nother species.

§ 9. *Of the use of sea-weed as a manure.*

Among green manures of great value and extensive application there remains to be noticed the sea-weed or sea-ware of our coasts. The marine plants of which it consists differ from the green vegetables grown upon land,—

1°. By the greater rapidity with which they undergo decay. When laid as top-dressings upon the land they melt down, as it were, and in a short time almost entirely disappear. Mixed with soil into a compost or with quicklime, they speedily crumble down into a black earth, in which little or no trace of the plant can be perceived.

2°. By the greater proportion of saline or other inorganic matter with these plants, in their dry state, contain. It is these substances which are obtained in the form of kelp when dry sea-weeds are burned in the air.

We have seen (Part II., p. 323,) that the quantity of ash left by 1000 lbs. of our more usually cultivated grasses, in the *dry* state, varies from 5 to nearly 10 per cent., but the *fucus vesiculosus*, which is reckoned the most valuable for the manufacture of kelp, gives upwards of 160; lbs. of ash from 1000 lbs. of the *dry* plant. This ash, according to Fagerström, consists of—

	lbs.
Gypsum - - - - -	63·4
Carbonate of Lime - - -	34·1
Iodide of Sodium - - - -	2·7
Other Salts of Soda - - -	29·9
Silica, Oxide of Iron, and earthy Phosphates	31·1
	161·2†

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* See note Part III., p. 193.

† *Berzelius Arsberättelse*, 1824, p. 225. If we compare the composition of

This ash contains less potash, but more soda and gypsum, than those of the grasses (Part II., p. 323,) and hence, as you will readily understand, may be expected to exercise a somewhat different influence upon vegetation.

It is of importance, however, to bear in mind that the saline and other inorganic matters which are contained in the sea-weed we lay upon our fields, form *a positive addition to the land.* If we plough in a green crop where it grew, we restore to the soil the same saline matter only which the plants have already taken from it during their growth, while the addition of sea-weed imparts to it an entirely new supply. It brings back from the sea a portion of that which the rivers are constantly carrying into it, and is thus valuable in restoring, in some measure, what rains and crops are constantly removing from the land.

Sea-weed is collected along most of our rocky coasts—and is seldom neglected by the farmers on the borders of the sea. In the Isle of Thanet, it is sometimes cast ashore by one tide and carried off by the next;—so that after a storm the teams of the farmers may be seen at work even during the night in collecting the weed, and carrying it beyond the reach of the sea.* In that locality, it is said to have doubled or tripled the produce of the land. On the Lothian coasts, a right of way to the sea for the col-

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this ash with that of the several varieties of *kelp*, given in Part III., p. 82, it will be seen to differ from them very considerably. But kelp is always manufactured from a mixture of different plants in varying proportions, and hence *one* cause of the diversity of composition among different samples of this substance.

Sprengel states (*Lehre vom Dünger*, p. 277,) that the *fucus vesiculosus* contains only 16 per cent of water. I do not know whether this is the result of experiments of his own, but I have not introduced it into the text, because it appears to me inconsistent with the remarkable manner in which sea-weed shrivels up when dried, and with its little permanence as a manure. "If an acre of land is completely covered with it, after a few days of dry weather, the whole would not weigh 500 lbs. The fibrous parts reduced to mere threads alone remain—so that *it is like manuring land with cobwebs.*" (Dr. Walker.) This would seem to imply the presence of a larger quantity of water in fresh sea-weed than in green grass, and consequently a less efficacy as a manure when applied in equal weights. According to Boussingault, the *fucus digitatus* contains 40 per cent. of water, and the *fucus saccharinus* 76 per cent. when newly taken from the sea, and 40 per cent. after being dried in the air.

* *British Husbandry*, II., p. 418.

lection of sea-ware increases the value of the land from 25s. to 30s. an acre.* In the Western Isles it is extensively collected and employed as a manure†—and on the North-east coast of Ireland, the farming fishermen go out in their boats and hook it up from considerable depths in the sea.‡

It is applied either immediately as a top-dressing, especially to grass lands—or it is previously made into a compost with earth, with lime, or with shell-sand. Thus mixed with lime, it has been used with advantage as a top-dressing for the young wheat crop,§ and with shell-sand, it is the general manure for the potato crop among the Western islanders.‖ It may also be mixed with farm-yard manure or even with peat moss, both of which it brings into a more rapid fermentation. In some of the Western Isles, and in Jersey, it is burned to a light, more or less coaly powder, and in this form is applied successfully as a top-dressing to various crops. There is no reason to doubt that the most economical method is to make it into a compost with absorbent earth and lime, or to plough it in at once in the fresh state.

In the Western Islands one cart load of farm-yard manure is considered equal in *immediate* effect—upon the first crop, that is—to 2½ of fresh sea-weed or to 1¾ after it has stood two months in a heap. The sea-weed, however, rarely exhibits any considerable action upon the second crop.

Sea-weed is said to be less suited to clay soils, while barren sand has been brought into the state of a fine loam by the constant application of sea-weed alone, for a long series of years.¶

Conflicting opinions are given by different practical men, in regard to the crops to which it is best suited. But the explanation of most of these and similar discordances is to be found in the answers to the three following questions—what substances does the crop specially require?—how many of these abound in the soil?—can the manure we are about to use supply all or any of the remainder? If it can, it may be expected to do good. Thus simply and closely are the kind of crop, the kind of soil, and the kind of manure, in most cases, connected together.

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* Kerr's *Berwickshire*, p. 377.

† "Sea-weeds constitute one-half of Hebridean manures, and nine-tenths of those of the remoter Islands."—Macdonald's *Agriculture of the Hebrides*, p. 401.

‡ Mrs. Hall's *Ireland*.

§ *British Husbandry*, II., p. 419.

‖ *Transactions of the Highland Society*, 1842-43, p. 766.

¶ Macdonald's *Hebrides*, p. 407.

§ 10. *Of manuring with dry vegetable substances.*

The main general difference between vegetable matter *of the same kind, and cut at the same age*, when applied as a manure in the green and in the dry state, consists in this—that in the former it decomposes more rapidly, and, therefore, acts more speedily. The *total* effect upon vegetation will probably in either case be very nearly the same.

But if the dry vegetable matter have been cut at a more advanced age of the plant or have been exposed to the vicissitudes of the weather while drying, it will no longer exhibit an equal efficacy. *A ton of dry straw, when unripe, will manure more richly than a ton of the same straw in its ripe state*—not only because the sap of the green plant contains the materials from which the substance of the grain is afterwards formed—but, because, as the plant ripens, the stem restores to the soil a portion of the saline, especially of the alcaline, matter it previously contained (Part II., p. 329). After it is cut, also, every shower of rain that falls upon the sheaves of corn or upon the new hay, washes out some of the saline substances which are lodged in its pores, and thus diminishes its value as a fertilizer of the land. These facts place in a still stronger light the advantages which necessarily follow from the use of vegetable matter in the recent state, for manuring the soil.

1°. *Dry straw.*—It is in the form of straw that dry vegetable matter is most abundantly employed as a manure. It is only, however, when already in the ground in the state of stubble, that it is usually ploughed in without some previous preparation. When buried in the soil in the dry state, it decomposes slowly, and produces a less sensible effect upon the succeeding crop; it is usually fermented, therefore, more or less completely, by an admixture of animal manure in the farm-yard before it is laid upon the land. During this fermentation a certain unavoidable loss of organic, and generally a large loss of saline matter also takes place.* It is, therefore, theoretically true of dry, as it is of green, vegetable matter, that it will add most to the soil, if it be ploughed in without any previous preparation.

Yet this is not the only consideration by which the practical man must be guided. Instead of a slow and prolonged action upon his crops, he may require an immediate and more powerful action for a shorter time, and to obtain this he may be justified in fermenting his straw with the certainty even of an unavoidable loss. Thus the disputed use of *short and long dung* becomes altogether a question of expediency or of practical economy. But to this point I shall again recur when treating of farm-yard manure in the succeeding lecture.

2°. *Chaff* partakes of the nature of straw, but it decomposes more slowly when buried in the soil in the dry state. It is also difficult to bring into a state of fermentation, even when mixed with the liquid manure of the farm-yard.

3°. *Rape-dust.*—When rape seed is exhausted of its oil, it comes from the press in the form of hard (rape) cakes, which, when crushed to powder, form the rape-dust of late years so extensively employed as a manure. It is occasionally mixed with farm-yard dung, and applied to the turnip crop, but its principal employment has hitherto been, I believe, as a top-dressing for the wheat crop, either harrowed in with the seed in October or applied to the young corn in spring.

Rape-dust requires moisture to bring out its full fertilizing virtues; hence it is chiefly adapted to clay soils or to such as rest upon a stiff subsoil. It is seldom applied, therefore, to the barley crop, and even upon wheat it will fail to produce any decidedly good effect in a very dry season. Several interesting circumstances have been experimentally ascertained in regard to the action of rape-dust, to which it is proper to advert:—

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* See in the succeeding lecture the section upon *mixed animal and vegetable manures.*

a. That in very dry seasons it may produce little benefit upon turnips, potatoes, and other crops, while in the same circumstances the effect of guano may be strikingly beneficial. Thus in one experiment, made in 1842, upon unmanured land sown with turnips—

16 cwt. of rape-dust gave	3¾	tons of bulbs per acre.
2 cwt. of guano gave	5	do.
Unmanured gave -	3½	do.

And in another, in the same season, upon unmanured land—

1 ton of rape-dust gave	14¼	tons of bulbs per acre.
3 cwt. of guano gave	23½	do.
Unmanured gave -	12¼*	do.

Again, upon potatoes, planted without other manure, in 3 experiments the produce per acre, *in tons*, was as follows:—

	Unmanured.	1 ton rape-dust.	3 cwt. guano.	4 cwt. guano.
White Don Potatoes	—	12¼	18½	—
Red Don Potatoes	6¾	10	—	14¼
Connaught Cups	5¾	13	—	13¼

In none of the above experiments did the action of the large quantity of rape-dust equal that of the comparatively small quantity of guano—though, from being buried in the soil, the difference was less striking in the case of the potato crops.

b. Rape-dust may actually cause the crop to be less than the land alone would naturally produce—if in a dry season it be laid on in any considerable quantity.

Thus in 1842, in an experiment upon *Oats*, made at Lennox Love—

16 cwt. of rape-dust gave	45	bushels.
2 cwt. of guano gave -	68	do.
Unmanured soil gave -	49	do.

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* See *Appendix*.

In this property of injuring the crop, when rain does not happen to fall, rape-dust resembles very much those saline substances which, as we have seen, may often be applied with much advantage to the land.

c. Yet it would appear to exercise less of this evil influence upon wheat and beans, even in similar circumstances. Thus in the same season, 1842, and in the same locality, Lennox Love, a crop of wheat, with—

16 cwt. of rape-dust gave	51	bushels per acre.
2 cwt. of guano gave -	48	do.
Unmanured gave - -	47½	do.

And a crop of beans, with—

16 cwt. of rape-dust gave	38	bushels.
2 cwt. of guano gave -	35½	do.
Unmanured gave - -	30	do.

In both of these cases, notwithstanding the drought, the rape-dust improved the crop, and though not sufficiently so to pay the cost of the application, yet to a greater extent than the same quantity of guano. It is deserving of investigation, therefore, whether rape-dust be more especially adapted to wheat and beans. Even in favourable seasons it may possibly prove more economical than guano as a manure for these two crops.*

d. But even in favourable seasons, and to the wheat crop, there is reason to believe that rape-dust cannot be *economically* applied in more than a certain, perhaps variable, quantity per acre. Thus four equal plots of ground (nearly half an acre each), sown with wheat, were top-dressed with rape-dust in different proportions with the following results:—

With 7 cwt. the produce was	26	bushels of market corn.
With 10 cwt. the produce was	28	do.
With 15 cwt. the produce was	29½	do.
With 26 cwt. the produce was	27¾	do.
Unmanured the produce was	22¼†	do.

In this experiment not only was the crop diminished when more than 15 cwt. was added, but *the increased pro-*

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* See *Appendix.*

† *British Husbandry*, II., p. 412.

duce was not sufficient to defray the additional cost of the application, when more than 7 cwt. of rape-dust was put on.

e. It may be noticed as another curious fact, that the action of rape-dust is dependant upon the presence or absence of certain other substances in the soil. Common salt and sulphate of soda, when mixed with it under certain circumstances, lessen the effect which it would produce alone, and the same will probably happen when it is applied, without admixture, to soils in which these saline compounds happen to be already present. Some remarks upon this interesting point will be found in the Appendix.

4°. *Lintseed, poppy-seed, cotton-seed, and cocoa-nut cakes.*—The cake which is left when other oils are extracted from the seeds or fruits in which they exist is also, in almost every case, useful as a manure. Thus the seeds of the cotton plant yield an oil and leave a cake which is now used as a manure in the United States, though little known as yet, I believe, in this country. The cocoa-nut cake is employed in Southern India partly in feeding cattle and partly as a manure for the cocoa-nut tree itself. Some trials have recently been made with it among ourselves, but I am ignorant of the precise results. In this country lintseed cake is made in large quantity, but as it is relished by cattle, is fattening, and enriches the droppings of the stock fed upon it, it is seldom applied directly to the land. In France and some parts of Belgium, where the poppy is largely cultivated for the oil yielded by its seeds, the cake which these seeds leave is highly esteemed as a manure.

5°. *Malt-dust.*—When barley is made to sprout by the maltster, and is afterwards dried, the small shoots and rootlets drop off, and form the substance known by the name of malt-dust. One hundred bushels of barley yield 4 or 5 bushels of this dust. It is sold at the rate of from 5s. to 8s. a quarter, and has been applied with success as a top-dressing to the barley and wheat crops. It may also be drilled in with turnips or dusted over the young grass in spring.

6°. *Saw-dust* is usually rejected by the agriculturist, in consequence of the difficulty which is generally experienced in bringing it into a state of fermentation. It decomposes slowly when ploughed into the soil in its dry state, but it nevertheless gradually benefits the land, and should not, therefore, be permitted in any case to run to waste. It forms an excellent absorbent also for liquid manures of any kind, which it preserves from sinking too rapidly when they are to be applied to porous, sandy, or chalky soils, while these liquids again hasten the decomposition of the saw-dust and augment its immediate effect upon the land. In localities favourable for the collection of sea-weed, it may also be more rapidly fermented by an admixture with this substance. Saw-dust forms an ingredient in some of the mixed manures which have recently come into use (see Appendix.)

7°. *Dry leaves* may either be dug into the land at once, or may be laid up in heaps, when they will gradually decay, and form, in most cases, an enriching manure. They gradually improve the soil (as we have already seen, Part III., p. 197) on which they annually fall, but the same quantity of leaves will do more good if collected and immediately dug in, or if made into a compost heap, than if left to undergo a slow natural decay on the surface of the land.

§ 12. *Of the use of decayed vegetable matter as a manure.*

The most abundant forms of partially decayed vegetable matter which come within the reach of the practical farmer, are peat and tanner's bark.

1°. *Peat.*—To soils which are deficient in vegetable matter, it is clear that a judicious admixture of peat must prove advantageous, because it will supply some at least of those substances which are necessary to the production of a higher degree of fertility. But peat decays very slowly in the air, and hence its *apparent* effect when mixed with the soil is very small. It may gradually ameliorate its quality especially if the soil be calcareous, but it will not immediately prepare the land for the growth of any particular crop. But if the obstacles to its further decomposition be removed—that is, if by artificial means its decay be promoted—then its immediate and apparent effect upon the soil is increased, and it becomes an acknowledged fertilizing manure. Different methods have been successfully practised for bringing it into this more rapid state of decay or fermentation.

a. The half-dried peat may be mixed with from one-fourth to one-half of its weight of fermenting farm-yard manure—the whole heap being carefully covered over with a layer of peat to prevent the escape of fertilizing vapours. By this method—first introduced to public notice by the late Lord Meadowbank—the entire mixture is gradually brought into an equable state of heat and fermentation, and as a manure for the turnip crop, is said to be as efficacious as an equal weight of unmixed farm-yard manure.

b. Or the liquid manure of the farm-yard may be employed for the same purpose, either in whole or in part. If the heap of mixed peat and dung be watered occasionally with the liquid manure, the fermentation will be more speedily effected, and at a less expense of common farm-yard dung. Or the half-dried peat may be used unmixed, as an absorbent for the liquid of the farm-yard, by which, without other aid, it will be brought into a state of fermentation with comparative rapidity.

c. Or instead of the liquid manure, the ammoniacal liquor of the gas-works may be employed, with less prominent benefit certainly, but still with great advantage.

d. Or the peat may be mixed with from one-sixth to one-fourth of its bulk of fresh sea-weed, the rapid decay of which will gradually reduce the entire heap into a fertilizing mass.*

e. Or rape-dust in the proportion of 1 ton to 30 cubic yards may be mixed with the half-dried peat from two to six weeks before the time of sowing the turnip crop. The fermentation of the rape-dust takes place so quickly, that this short time is usually sufficient to convert the whole into a uniform and rapidly decaying mass.

In short it is only necessary to mix *half-dried* peat with any substance which undergoes rapid spontaneous decomposition—when it will more or less speedily become infected with the same tendency to decay, and will thus be rendered capable of ministering to the growth of cultivated plants.

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* *British Husbandry*, II., p. 417.

2°. *Tanner's bark* is still more difficult to reduce or to bring into a rapid state of decomposition. Any of the methods above recommended for peat, however, will to a certain extent succeed also with the spent bark of the tan pits. But in the case of substances so solid and refractory as the lumps of bark are, the admixture of a quantity of lime and earth, so as to form a compost heap, is perhaps, the most advisable mode of procedure. The way in which lime promotes the decay of woody fibre in such heaps has already been explained (see Part III., p. 130.)

§ 13. *Use of charred vegetable matters as a manure.*

Soot and charcoal are the principal substances of this class which have been more or less extensively employed for the purpose of increasing the productiveness of the land.

1°. *Soot* is a complicated and variable mixture of substances produced during the combustion of coal. Its composition, and consequently its effects as a manure, vary with the quality of the coal, with the way in which the coal is burned, and with the height of the chimney in which it is collected.

Soot has not been analyzed since the year 1826, when a variety examined by Braconnot was found by him to consist in a thousand parts of

Ulmic Acid? (a substance resembling that portion of the vegetable matter of the soil which is soluble in caustic potash—see Part II., p. 406)	302·0
A reddish brown soluble substance, containing nitrogen, and yielding ammonia when heated	200·0
Asboline	5·0
Carbonate of lime, with a trace of magnesia (probably derived in part from the sides of the chimney)	146·6
Acetate of lime	56·5
Sulphate of lime (gypsum)	50·0
Acetate of magnesia	5·3

Phosphate of lime, with a trace of iron	15·0
Chloride of potassium	3·6
Acetate of potash	41·0
Acetate of ammonia	2·0
Silica (sand)	9·5
Charcoal powder	38·5
Water	125·0
	1000[*]

The earthy substances which the soot contains are chiefly derived from the walls of the chimney, and from the ash of the coal, part of which is carried up the chimney by the draught. These, therefore, must be variable, being largest in quantity where the draught is strongest and where the earthy matter or ash in the coal is the greatest. The quantity of gypsum present depends upon the sulphur contained in the coal,—that which is freest from sulphur will give a soot containing the least gypsum. The ammonia and the soluble substance containing nitrogen will vary with the quantity of nitrogen contained in the coal and with certain other causes—so that the composition of different samples of soot may be very unlike, and their influence upon vegetation therefore very unequal. The consequence of this must be, that the results obtained in one spot, or upon one crop, are not to be depended upon, as indicative of the *precise* effect which another specimen of soot will produce in another locality, and upon another crop even of the same kind. And thus it happens that the use of soot is more general, and is attended with more beneficial effects, in some districts than in others.

a. In general it may be assumed that where ammonia or its salts will benefit the crop, soot also will be of use, and hence its successful application to grass lands. From its containing gypsum it should also especially benefit the clover crops. Yet Dr. Anderson says, "I have used soot as a top-dressing for clover and rye-grass in all proportions, from one hundred bushels per acre to six hundred, and I cannot say that ever I could perceive the clover in the least degree more luxuriant than in the places where no soot had been applied. But upon rye-grass its effects are amazing, and increase in proportion to the quantity so far as my trials have gone."[*] And his general conclusion is, that *soot does not affect the growth of clover in any way, while it wonderfully promotes that of rye-grass.* Will any of you, by experiment, ascertain if such be really the case with the soot of your own neighbourhood?

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[*] *Annales de Chemie et de Physique*, xxxi., p. 37.

b. The presence of ammonia in soot causes it, when laid in heaps, to destroy all the plants upon the spot; and Dr. Anderson adds the interesting observation, "that the first plant which appears afterwards is *constantly* the common couch-grass (*triticum-repens.*)[†]

c. This ammonia also causes soot to injure and diminish the crop in very dry seasons. Thus the produce of a crop of beans, after oats, in 1842, upon an

Unmanured part of the field was - - -	29½ bushels.
Dressed with 4 bushels of soot - - - -	28 bushels.[‡]

It also diminished, in a small degree, the potato crop in the same year in the experiments of Lord Blantyre, at Erskine (See Appendix)—

With manure alone, the produce was - - -	11 tons 17 cwt.
With 30 bushels of soot sprinkled over the dung	11 tons 4 cwt.

Like rape-dust (Part III., p. 204) and saline substances, therefore, soot seems to require moist weather, or a naturally moist soil, to bring out all its virtues.

d. Yet even in the dry season of 1842, its effect upon wheat and oats in the same locality (Erskine) was very beneficial. Thus the comparative produce of these crops, when undressed and when top-dressed with 10 bushels of soot per acre, was as follows:—

Unmanured - - - -	Wheat 44 - -	Oats 49.
Top-dressed with soot -	Wheat 54 - -	Oats 55

But the dressed wheat was inferior in quality to the undressed—the former weighing only 58, the latter 62 lbs. a bushel. In the oats there was no difference. Are we to infer from these results that, even in dry seasons, soot may be safely applied to crops of corn, while to pulse and roots it is sure to do no good? Further precise observations, no doubt, are still necessary—and the more especially as the experiments upon oats and wheat, made in the still drier locality of Lennox Love (Appendix), gave a decrease in the produce of grain—while in Mr. Fleming's experiments upon turnips (Appendix), 50 bushels of soot, applied alone, gave an increase of 4 tons in the crop.

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[*] Dr. Anderson's *Essays* (edit. 1800), ii., p. 304.

[†] Ibid, p. 305.

[‡] See *Appendix*.

e. An experiment of Lord Blantyre's (Appendix) enables us to judge of the efficacy of soot in a dry season, compared with that of nitrate of soda and of guano upon the produce of hay. Thus the crop of hay, per imperial acre, from the

			Cost.		
	tons.	cwts.	£.	s.	d.
Undressed portion, weighed	1	8 . .	——		
Dressed with 40 bushels of soot . .	1	15 . .	0	11	8
————160 lbs. nitrate of soda .	1	19 . .	1	15	9
————160 lbs. of guano . . .	2	2 . .	1	15	9

In this experiment the soot proved a more profitable application than either of the other manures.

f. In regard to this substance, I shall only advert to one other observation—but it is an important one—made by Mr. Morton, when describing the management of a well conducted farm in Gloucestershire.* "The quantity of soot used upon this farm amounts to 3000 bushels a year, one-half of which is applied to the potato, the other half to the wheat crop." *All the straw grown upon this farm is sold for thatch*, and for the last 30 years the only manure that has been purchased to replace this straw is the soot, which is brought from Gloucester, Bristol,† and Cheltenham. Soot no doubt contains many things useful to vegetation, yet where *all* the produce is carried off, and soot only added in its stead—even the rich soils of the vale of Gloucester cannot be expected to retain a perpetual fertility. The slow changes which theory indicates may altogether escape the observation of the practical man, who makes no record of the *history* of his land, and yet may be ever slowly proceeding.

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* That of Mr. Dimmery, described in the *Journal of the Royal Agricultural Society*, I., p. 400.

† At Bristol the price of soot is 9d. a bushel, at Gloucester only 6d., yet the former is preferred, even at the higher price. It is of better quality. owing, it is said, to the greater length of the chimnies—it may be also to the quality of the coal and to the way it is burned.

2°. *Charcoal.*—Wood-charcoal, from its porous nature, and its tendency to absorb animal odours and other unpleasant effluvia (Part I., p. 27), has been found, when reduced to fine powder, to be an excellent admixture for night-soil, for liquid manure, and for other substances which undergo putrescent decay. It is therefore employed to a considerable extent by the manufacturers of artificial manures. It is also applied with advantage in some cases as a top-dressing to various crops*—its efficacy being probably due in part to its power of absorbing from the air, or of retaining in the soil, those gaseous substances which plants require, and in part to the slow decay which it is itself capable of undergoing. In moist charcoal powder seeds are said to germinate with great ease and certainty.

3°. *Coal-tar.*—Another product of coal, the tar of the gas-works, has recently been recommended as an admixture for peat and similar composts, and it is one of the substances with which Mr. Daniel impregnates his saw-dust in the manufacture of his patent manure. It is impossible to say how much of the good effect derived from the use of such mixtures as that described in the Appendix, is due to the coal-tar they contain,—and as no experiments have hitherto been made from which the true action of coal-tar can be inferred, it may still be considered as a matter of doubt whether it can at all add directly to the fertility of the soil.

§ 14. *Of the theoretical value of different vegetable substances as manures.*

Vegetable manures are known to differ in fertilizing virtue. Thus, 1 ton of rape-dust is said to be equal to 16 of sea-weed or to 20 of farm-yard manure. On what principles do these unlike fertilizing virtues depend ?

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* See Mr. Fleming's experiment upon Swedes (Appendix), in which 50 bushels of charcoal powder increased the crop by 3 tons an acre.

1°. According to Boussingault and other French authorities, *the relative efficacy of all manures depends upon the proportions of nitrogen they severally contain.*[*] And taking farm-yard manure—consisting of the mixed droppings and litter of cattle—as a standard, they arrange vegetable substances as manures in the following order of value:—

	Equal effects are produced by	
Farm-yard manure	1000	lbs.
Potatoe and turnip(?) tops	750	··
Carrot tops	470	··
Natural grass	760	··
Clover roots	250	··
Fresh sea-weed	450 to 750	··
Sea-weed dried in the air	300	··
Pea straw	220	··
Wheat straw	750 to 1700	··
Oat straw	1400	··
Barley straw	1750	··
Rye straw	1000 to 2400	··
Buck-wheat straw	850	··
Wheat chaff	470	··
Fir saw-dust	1700 to 2500	··
Oak do.	750	··
Soot, from coal	300	··
Lint and rape-dust	80	··

The numbers in this table agree with the results of experiment in so far as they indicate that green substances generally, when ploughed in as manures, should enrich the soil more than an equal weight of farm-yard manure—that the roots of clover should be more enriching still—and that sea-weed is likewise a very valuable manure. They agree also with practical observation in placing pea and probably bean straw, far above the straws of wheat, oats, &c., in fertilizing power, and in representing soot and rape-dust is more powerful than any of the other substances in the table. So far, therefore, a certain *general* reliance may be placed upon the fertilizing value of a substance as represented by the proportion of nitrogen it contains.

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[*] *Annales de Chemie et de Phys.*, 3d Series, III., p. 76.

But if we bear in mind that plants, as we have frequently had occasion to mention, require inorganic as well as organic *food*, it is quite clear that the mere presence of nitrogen in a substance is not sufficient to render it highly nutritive to growing plants. Otherwise the salts of ammonia would be the richest manures of all, and would best nourish and bring to perfection every crop and in all circumstances—which experience has proved to be by no means the case. Hence

2°. The value of vegetable substances as manures *must depend in some degree upon the quantity and kind of inorganic matter they contain.* In reference to the quantity of inorganic matter which they respectively impart to the soil, their relative values are represented by the following numbers:—

	One ton contains of inorganic matter about
Potato tops, green	26 lbs.
Turnip tops, do.	48 ..
Carrot tops, do.	45 ..
Rye-grass, do.	30 ..
Vetch, do.	38 ..
Green sea-weed do.	22 ..
Hay	90 to 180 ..
Pea straw	100 ..
Bean straw	60 to 80 ..
Wheat straw	70 to 360 ..
Oat straw	100 to 180 ..
Barley straw	100 to 120 ..
Rye straw	50 to 70 ..
Fir saw-dust	6 ..
Oak saw-dust	5 ..
Soot	500 ..
Rape-dust	120 ..

This table places the several vegetable substances in an order of efficacy considerably different from the former, in which they are arranged according to the quantity of nitrogen they respectively contain. We *know* that wood ashes (Part III., p. 77), kelp, and the ashes of straw (Part III., p. 84), do promote the fertility of the land, and therefore the absolute as well as the relative efficacy of the above vegetable substances must depend in some degree upon the quantity of inorganic matter they contain. But we should be wrong were we to ascribe the *total* effect of any of them to the inorganic matter alone.

3°. Even the carbonaceous matter of plants contributes its aid in increasing the produce of the soil by supplying, either directly or indirectly, a portion of the necessary food of plants. This has already been shown in various parts of the preceding lectures.

It is the property of substances which contain a larger proportion of nitrogen to undergo rapid decay in the presence of air and moisture, and thus to produce a more immediate and sensible action upon growing plants. But the carbon changes more slowly, and the inorganic matter also separates slowly from decaying vegetables in the soil —and hence the apparent effects of these constituents are less striking. *Thus the immediate and visible effect of different vegetable substances, in the same state, is measured by the relative quantities of nitrogen they contain—their permanent effects by the relative quantities of inorganic and of carbonaceous matters.* In the case of rape-dust for example, the immediate effect is determined chiefly by its nitrogen—the permanent effects, by the ash it leaves when burned, or when caused to undergo complete decay in the air.

LECTURE XVIII.

Animal manures. Flesh, blood, and skin. Wool, woollen rags, hair, horn, and bones. On what does the fertilizing action of bones depend? Animal charcoal and the refuse of the sugar refineries. Fish and fish refuse, whale blubber and oil. Relative fertilizing value of the substances previously described. Pigeon dung. Dung of sea-fowl—guano. Liquid manures—the urine of various animals. Mixed animal and vegetable manures. Night soil, the droppings of the horse, the cow, the pig. Effects of digestion upon vegetable food. Why equal weights of vegetable matter and of the droppings of animals fed upon it possess different fertilizing powers. Farm-yard dung. Weight of dung produced from a given weight of grass, straw, and other produce. Loss undergone by farm-yard manure during fermentation. Improvement of the soil by irrigation.

Animal substances have always been considered as more fertilizing to the land than such as are of vegetable origin. Their action is in general more immediate and apparent, and it takes place within such a limited period of time that the farmer can calculate upon its being exercised in benefitting the crop to which it is applied. The reason of this more immediate action will presently appear.

§ 1. *Of flesh, blood, and skin.*

1°. *Flesh.*—The flesh of animals is not only a rich manure in itself, but the rapidity with which it undergoes decay in our climate enables it speedily to bring other organic substances with which it may be mixed into a state of active fermentation. It is only the flesh of such dead animals, however, as are unfit for food that can be economically applied to the land as a manure.

The flesh of animals consists of a *lean* part, called the muscular fibre, or by chemists fibrin, and a *fatty* part, intermixed with the lean in greater or less proportion, according to the condition of the animal. Of these two it is the lean part which acts most immediately and most energetically in the promotion of vegetation. Lean beef, in the recent state, contains 77 per cent. of its weight of water, so that 100 lbs. consist of 77 lbs. of water and 23 lbs. of dry animal matter.

2°. *Blood.*—The blood of animals is more extensively employed as a manure. It is carried off in large quantities from the slaughter-houses of the butchers, and makes rich and fertilizing composts. In some parts of Europe it is dried, and in the state of dry powder is applied with much effect as a top-dressing to many crops.

Liquid blood consists of fibrin—the substance of lean meat, of albumen—the same as the white of eggs—of a red colouring matter, and of certain saline substances dissolved in a considerable quantity of water. When blood cools it gradually congeals, and separates into two parts, a gelatinous red portion, called the *clot*, and a liquid, nearly colourless part, called the *serum*. The clot contains most of the fibrin and colouring matter, and a portion of the albumen; the serum, the greater part of the albumen and of the soluble saline substances which are present in the blood.

The relative composition of fresh muscular fibre and of liquid blood is thus represented in 100 parts:—

	Water.	Dry animal matter.
Muscular fibre - - -	77	- - - 23
Blood - - - - - - -	79	- - - 21*

It appears singular that the solid muscle of animals should contain so nearly the same quantity of water as their liquid blood does.

But it is no less striking that the dry animal matter which remains, when lean muscular fibre and when blood are fully dried, has nearly the same apparent composition. Thus, according to the analyses of Playfair and Boeckman, dry flesh and dry blood consist respectively of—

	Dry beef.	Dry ox blood.
Carbon - -	51·83	- - - 51·96
Hydrogen -	7·57	- - - 7·25
Nitrogen -	15·01	- - - 15·07
Oxygen - -	21·37	- - - 21·30
Ashes - -	4·23	- - - 4·42
	100	100†

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* Thomson's *Animal Chemistry*, pp. 285 and 367.

† Liebig's *Organic Chemistry applied to Physiology*, p. 314.

The *organic* part, therefore, of blood and of flesh is nearly identical in ultimate composition, and the *final* result of equal weights of each, when applied as manures, should be nearly the same. The ashes, however, or inorganic part, though present in each nearly in the same proportion (4·23 and 4·42 per cent.), are somewhat different in composition, and therefore the action of blood and flesh will be a little unlike in so far as it depends upon the saline substances they are respectively capable of conveying to the roots of plants.

3°. *Skin.*—The skins of nearly all animals find their way ultimately into the soil as manure, in a more or less changed state.

The refuse parings from the tan-yards, and from the curriers' shops, though usually employed for the manufacture of glue are sometimes used as a manure, and with great advantage. They may either be ploughed in sufficiently deep to prevent the escape of volatile matter when they begin to decay, or they may be made into a compost by which their entire virtues will be more effectually retained.

Skin differs considerably in its constitution from flesh and blood. It contains, in the recent state, about 58 per cent. of water, and leaves, when burned, only 1 per cent. of ash. The combustible or organic part consists of—

Carbon - - -	50·99
Hydrogen - - -	7·07
Nitrogen - - -	18·72
Oxygen - - -	23·22
	100

It contains, therefore, 3½ per cent. more nitrogen than flesh or blood. So far as the fertilizing action of these substances depends upon the proportion of this constituent—glue, the parings of skins, and all gelatinous substances will consequently exhibit a greater efficacy than flesh or blood.

§ 2. *Wool, woollen-rags, hair, horn, and bones.*

1°. *Wool,* in the form of the waste of the spinning-mills, and especially in that of woollen rags, acts very efficaciously as a manure. The rags are used with good effect upon light chalks and gravels, in which they retain the water. They are sometimes ploughed in for wheat along with the clover stubble, in the winter with the corn stubble, when the land is intended for turnips, and are sometimes applied as a top-dressing to clover and grass lands.* They are used most extensively, however, in the hop-grounds, being dug in round the roots, to which they continue for a long time to supply much nourishment. The estimation in which they are held may be judged of by the price they bring, which is from £5 to £10 a ton.

2°. *Hair* also is fitted to produce effects similar to those which follow the use of wool. It can seldom, however, be obtained by the farmer at so economical a rate as to enable him to trust to it as an available resource when other manures become scarce.

3°. *Horn*, in the form of horn shavings, parings, and turnings, is justly considered as a very powerful manure. Even in the state of shavings, however, it undergoes decay still more slowly than woollen rags; and, therefore, like them, will always be most safely and economically employed when previously rotted, by being made into a compost.

Wool, hair, and horn, differ from flesh, blood, and skin, by containing very much less water in their natural state, and by undergoing, in consequence, a much slower decay, and exhibiting a much less *immediate* action upon any crop to which they may be applied. The intelligent farmer, therefore, will bear this important distinction in mind, in any opinion he may form as to the relative efficacy of these several substances as general fertilizers of the land.

In chemical composition, these three substances are nearly identical, and they do not differ widely from the lean of beef or from dried blood. When burned they leave only a small quantity of ash:—

	Of ash.	
Wool leaves	2·0	per cent.
Hair	0·72	..
Horn	0·7	..

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* *British Husbandry*, I., p. 496.

And the part which burns away—the organic part—consists of—

	Wool.	Hair.	Horn.
Carbon	50·65	51·53	51·99
Hydrogen	7·03	6·69	6·72
Nitrogen	17·71	17·94	17·28
Oxygen and Sulphur	24·61	23·84	24·01
	100	100	100

The organic part of these three substances, therefore, is nearly identical in composition, and hence, when equally decomposed they ought to produce the same effects upon the young crops. They contain a little more nitrogen than dried flesh and blood, and a little less than dried skin, and therefore in so far as their fertilizing action depends upon this element, they ought to occupy an intermediate place between these several substances.

§ 3. *Of the composition of bones.*

Few substances have of late years done so much to increase the agricultural produce of various parts of England as the use of crushed bones for manuring the land.

1°. Recent bones contain a variable quantity of water and fat. The proportion of fat depends upon the position of the bone in the body, and upon the condition of the animal. The proportion of water depends partly upon the solidity of the bone and partly upon its age. According to Denis, the radius of a female,

	Water, with a little fat.
Aged 3 years, contained	33·3 per cent.
Aged 20 years, do.	13·0 do.
Aged 78 years, do.	15·4 do.

The quantity of water thus present in bones performs an important part in determining the action which bone-dust is known to exercise upon the land. The oil is sometimes extracted by boiling the bones. During this boiling they absorb more water, and thus, when laid upon the land, undergo a more rapid decomposition, and exercise, in consequence, a more immediate and apparent, and therefore, as some may think, a more powerful fertilizing action.

2°. But bones differ from the other animal substances already described chiefly by containing a much larger proportion of inorganic matter, or by leaving, when burned, a greater per-centage of ash. The quantity of inorganic matter, however, contained in bones is not constant. It is less in the young than in the full-grown animal—less in the spongy than in the compact or more solid bones—and less in those of some animals than in those of others. Thus, when freed from fat and perfectly dried—

	Of inorganic matter.
The lower jaw-bone of an adult .	left 68·0 per cent.
———————— a child of three years	— 62·8 ····
A compact human bone	— 58·7 ····
A spongy human bone	— 50·2 ····
The tibia of a sheep	— 48·03 ····
The vertebræ of a haddock . .	— 60·51 ····

It is obvious that the relative efficacy of equal weights of bones must be affected by such differences in the relative proportions of organic and inorganic matter which they severally contain.

3°. This inorganic matter or ash consists in great part of phosphate of lime (earth of bones, Part II., p. 289), but it contains also a considerable though variable proportion of carbonate of lime, with smaller quantities of several other ingredients. The proportion of carbonate of lime appears to be smallest in carnivorous animals.

Thus, for every 100 parts of phosphate of lime their exists in—

		Carbonate of lime.
Human bones about . .		20·7
Bones of the sheep		24·1
Do.	ox . . .	13·5
Do.	fowl . . .	11·7
Do.	haddock . .	6·2
Do.	frog . . .	5·8
Do.	lion . . .	2·6

These proportions are not to be considered as constant—because it varies not only in the different bones of the same animal but also in bones from the same part of the body of different animals of the same species.* But the existence of such differences must render unlike the fertilizing action of the bones of different animals—if, as many think, this action depends in any great degree upon the quantity of phosphate of lime which they respectively contain.

4°. Besides the phosphate and carbonate of lime, I have stated that bones contain certain other inorganic substances, which are found in small quantity in the ash. What these substances are will appear in the following table, which represents the constitution of the bones of some animals, as analyzed by Dr. Thomson—

	Ileum of a sheep.	Ileum of an ox.	Vertebræ of a haddock.
Organic or combustible matter	43·3	48·5	39·5
Phosphate of lime	50·6	45·2	56·1
Carbonate of lime	4·5	6·1	3·6
Magnesia	0·9	0·2	0·8
Soda	0·3	0·2	0·8
Potash	0·2	0·1	——
	99·8	100·3	100·8

The soda exists in bones probably in the state of common salt, and the magnesia in that of phosphate. An appreciable quantity of fluoride of calcium, with traces of iron and magnesia, are also generally found in bones, in addition to the substances indicated in the preceding analyses.

5°. When bones are heated to redness in the open air the organic part burns away, and leaves the white earthy matter in the form, and nearly of the bulk, of the original bone. But if a dry bone be covered with dilute muriatic acid, the earthy or inorganic part is slowly dissolved out, and the organic part—the cartilage or gelatine—will alone remain, retaining also the form and size of the organic bone. In this state it is flexible and somewhat soft, and by prolonged boiling may be dissolved in water, and manufactured into glue.

This organic or combustible part of bones is identical in chemical composition with skin and glue, and is nearly the same as wool, hair, and horn, of which the analysis has already been given. In so far, therefore, as their efficacy depends upon the organic constituent, dry bones must be greatly inferior to an equal weight of any of the other animal substances above described, because of the much greater proportion of earthy matter they contain.

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* Thomson's *Animal Chemistry*, p. 242.

§ 4. *On what does the fertilizing action of bones depend?*

Bones contain, as we have seen, a large proportion both of organic and of inorganic matter;—on which of these two constituents does their fertilizing action most depend? Some regard the phosphate of lime or bone earth, as the only source of the benefits so extensively derived from them—and it is by supposing the soil to be already sufficiently impregnated with this phosphate that Sprengel accounts for the little success which has attended the use of bones in Mecklenburgh and North Germany. Others, again, attribute the whole of their influence to the organic part—the gelatine—which bones contain. Neither of these views is strictly correct. Plants, as we have seen, require a certain quantity of phosphoric acid, lime, and magnesia which are present in the inorganic part of bones; and so far, therefore, are capable of deriving inorganic food from bone-dust. But the organic part of bones will decompose, and therefore will act nearly in the same way as skin, wool, hair, and horn do—which substance it resembles in ultimate composition.[*] It cannot be doubted, therefore, that a considerable part of the effect of bones upon all crops must be due to the gelatine which they contain.

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[*] The main difference is in the quantity of sulphur contained in hair. An analysis of human hair, by VAN LAER (*Annalen der Pharmacie*, xlv., p. 168), which has reached me since the preceding sheet went to press, shows the proportion of sulphur more accurately that which is given at the top of (Part III.) p. 221. He found human hair of various colours to leave from one-third to nearly two per cent. of ash when burned, and to consist besides of—

Carbon	50·65
Hydrogen	6·36
Nitrogen	17·14
Oxygen	20·85
Sulphur	5·00
	100

and nearly half a per cent. of phosphorus.

The principal facts, now known in regard to the action of bones, may be thus stated :—

1°. The organic matter of bones acts like that of skin, woollen rags, horn-shavings, &c., but as bone-dust contains only about one-third of the organic matter which is present in an equal weight of either of the above substances, its total effect, in so far as it depends upon the organic matter, will be less in an equal proportion.

2°. But as the organic matter of bones contains more water than horn or wool,* it will decay more rapidly than these substances when mixed with the soil, and will therefore be more immediate in its action. Hence, the reason why woollen rags and horn-shavings must be ploughed in in the preceding winter, if they are to benefit the subsequent wheat or turnip crops, while bone-dust can be beneficially applied at the sowing of the seed.

3°. When bones are boiled the oil will be separated, and a portion of the gelatine will at the same time be dissolved out.† The bones, therefore, will be in reality rendered less rich as a manure. But as they at the same time take up a considerable quantity of water, boiled bones will decompose more rapidly when mixed with the soil, and thus will appear to act as beneficially as unboiled bones. Hence the reason why in Cheshire, where boiled bones are used to a considerable extent, many practical men are of opinion that their action upon the crops is not inferior to that of bones from which the oil has not been extracted by boiling. The *immediate* effect may indeed be equal, or even greater, than that of unboiled bones, but the *total* effect must be less in proportion to the quantity of organic matter which has been removed by boiling. Cases, however, may occur in which the skilful man will prefer to use boiled bones because they are fitted to produce more immediate effect where—as in the pushing forward of the young turnip plant—such an effect is particularly required.

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* Above, (Part III.) p. 221.

† The prolonged boiling of bones, so as to dissolve a portion of the gelatine, is practised to a considerable extent as a mode of manufacturing size or glue. In the large dying establishments in Manchester, the bones are boiled in open pans for 24 hours, the fat skimmed off and sold to the candle-makers, and the size afterwards boiled down in another vessel till it is of sufficient strength for stiffening the thick goods for which it is intended. The size liquor, when exhausted, or no longer of sufficient strength for stiffening, is applied with much benefit as a manure to the adjacent pasture and artificial grass lands, and the bones are readily bought up by the Lancashire and Cheshire farmers. The boiled bones must evidently lose all the fertilizing virtue which the size liquor acquires.

4°. When bones are buried in a more or less entire state, as they occasionally are about the roots of vines and fruit trees, they gradually decay, and sensibly promote the growth of the trees to which they are applied. Yet after the lapse of years these same bones may be dug up nearly unaltered either in form or in size. The bones of a bear and of a stag, after being long buried were found by Marchand to consist of—

	Bones of the bear buried		Femur of a
	deep.	shallow.	stag.
Animal matter - -	16·2	4·2	7·3
Phosphate of lime - -	56·0	62·1	54·1
Carbonate of lime - -	13·1	13·3	19·3
Sulphate of lime - -	7·1	12·3	12·2
Phosphate of magnesia -	0·3	0·5	2·1
Fluoride of calcium -	2·0	2·1	2·1
Oxides of iron and manganese	2·0	2·1	2·9
Soda - - - -	1·1	1·3	—
Silica - - - -	2·2	2·1	—
	100	100	100

The most striking change undergone by these bones was the large loss of organic or animal matter they had suffered. The relative proportions of the phosphate and carbonate of lime had been comparatively little altered. The *main* effect, therefore, produced by bones when buried at the roots of trees, and their *first* effect in all cases, must be owing to the animal matter they contain—the elements of this animal matter, as it decomposes, being absorbed by the roots with which the bones are in contact.

Such facts as this prove, I think, the incorrectness of the one-sided opinion too hastily advanced by Sprengel, and after him reiterated by Liebig and his followers—that the principal efficacy of bones is, in all cases, to be ascribed to their earthy ingredients, and especially to the phosphate of lime.

This opinion of Sprengel rests mainly on two facts put forward by himself.* Bones, he says, have failed to produce in North Western Germany the good effects for which they are so noted in England, yet in the same districts, farm-yard and other animal manures exhibit their usual fertilizing action. It cannot, therefore, he concludes, be the *animal matter* of bones to which their beneficial influence is to be ascribed. But to this conclusion we may fairly demur, when we know how often on heavy and undrained lands bone-dust fails even among ourselves. Let bones be tried for the turnip crop—a crop still almost unknown in Northern Germany—and upon well drained soils similar to those of our best turnip lands, and I venture to predict, in opposition to Sprengel's experience, that bones will no longer fail even in Mecklenburg.

Again, having drawn his conclusion in regard to the inutility of the animal matter, Sprengel states that the marl which is applied to the land in Holstein and the neighbouring province, contains phosphate of lime (Part III., p. 104), and hence the reason why the *earthy matter* of the bones applied does not improve the land. In so far as the efficacy of bones really depends upon their earthy constituents, the use of a marl containing phosphate of lime† will, no doubt, greatly supersede them;—but in so far as it depends upon the animal matter they contain, bones will exhibit their natural fertilizing action, however rich the soil may already be in those compounds of which their earthy or incombustible part consists.

5°. Yet there is reason to believe—nay it may be assumed as certain—that the phosphate and carbonate of lime which bones contain so largely, are not without effect in promoting vegetation. All our cultivated plants require and contain both phosphoric acid and lime,‡ and from the vegetables on which they feed, all animals derive the entire substance of their bones. This same phosphoric acid and lime, therefore, must exist in the soil on which the plants grow, or they will neither thrive themselves nor be able properly to nourish the animals they are destined to feed. If a soil, then, be deficient in phosphate of lime or its constituents, it is clear that the addition of bones will benefit the after-crops not only by the animal but by the earthy matter also which they contain. And that such is the case, in many instances, there is good reason for believing. · But that this can by no means account for the whole effect of bones, even supposing the soil to which they are applied to be, in every instance, deficient in phosphates, is clear from the fact (see Part II., p. 327), that 260 lbs.—less than 6 bushels—of bone-dust per acre are sufficient to supply all the phosphates contained in the crops which are reaped during an entire four-shift rotation of turnips, barley, clover, and wheat. Yet the quantity of bones actually applied to the land is from three to five times the above weight, repeated every time the turnip crop comes round.

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* *Lehre vom Dünger*, p. 153.

† Most lime-stones and shell-sands contain an appreciable quantity of this phosphate, and will, therefore, to the same extent supersede the use of the earthy matter of bones. Much of the marl of Holstein consists of the detritus of chalk rocks, anciently broken up and carried off—by the waters of the sea with which that part of Europe was covered at no very remote geological epoch.

‡ See Part II, p. 318 to p. 324.

6°. Still, granting that the chief effect of bones upon the immediately succeeding crops is due to their organic part, upon what does their *prolonged* good effect depend? Some lands remember a single dressing of bones for 16 or 20 years, and some after the application of 2 or 2½ tons of bones have yielded 10 to 15 successive crops of oats, and have been sensibly benefitted for as many as sixty years after the bones were applied.*

This prolonged effect is also due in part to both constituents. When not crushed to powder, the organic matter of bones is always slow in disappearing, and slower the deeper they are buried. In some soils, also, the process is more slow than in others. The long buried bones of the bear and of the stag, of which the analysis is given above (Part III., p. 226), had lain in the soil for an unknown period, and yet they still contained a sensible proportion of animal matter. So it is with the bones used for manure, when they are not crushed too fine. They long retain a portion of their organic matter, which they give out more slowly, and in smaller quantity, every year that passes, yet still in such abundance as to contribute sensibly to the nourishment, and in some degree to promote the growth, of the crops which the land is made to bear.* So it would be with the horns and hoofs of cattle, if laid on in equal quantity, for they also decay with exceeding slowness.

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* See *Appendix*, and *British Husbandry*, I., p. 398.

Still the inorganic part is not without its use. *If the soil be deficient in phosphates or in lime*, the earthy matter of the bones will supply these substances. I only wish to guard you against the conclusion, that because bones often act for so long a period, that therefore the organic matter can have no share in the influence they exercise after a limited period of years.

He who candidly weighs the considerations above presented will, I think, conclude that the whole effect of bones cannot in any case be ascribed exclusively either to the one or to the other of their principal constituents. He will believe, indeed, that in the turnip husbandry the organic part performs the most prominent and most immediately useful office, but that the earthy part, nevertheless, affords a ready supply of certain inorganic kinds of food, which in many soils the plants would not otherwise easily obtain. He will assign to each constituent its separate and important function, being constrained, at the same time, to confess—that while in very many cases the *earthy part of bones, applied alone*, would fail to benefit the land, there are few cultivated fields in which the *organic part applied alone* would not materially promote the growth of most of our artificial crops.

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* This opinion derives a singularly interesting confirmation from the fact that a portion of the soil of an arable district in Sweden, "which from time immemorial had grown excellent wheat without manure," was found by Berzelius to contain minute fragments of bone capable upon boiling with water of yielding a weak solution of gelatine. It was concluded, therefore, that the spot had been an ancient battle field, and that its prolonged fertility was due to the bones of old time buried in it, and still to some extent undecomposed (Marchand).

§ 5. *Of the application of bone-dust to pasture lands.*

If the soil be deficient in phosphate of lime, bone-earth alone, or the mineral phosphate (Part II., p. 293) may be advantageously applied to increase its fertility. In a four-years rotation of turnips, barley, clover, and wheat, if bones be used for the turnip crop, the land will every rotation become richer in bone-earth,* and therefore the application of earthy phosphates cannot—after a few rotations—be expected materially to affect its productiveness. But pasture lands are treated differently, and it is not unlikely that in some instances the earth of bones, even applied alone, may to such lands be productive of considerable benefit.

The application of bone-dust to permanent pasture has of late years been practised with great success in Cheshire. Laid on at the rate of 30 to 35 cwt., ar at a cost of £10 per acre, it has increased the value of old pastures from 10s. or 15s. to 30s. or 40s. per acre: and after a lapse of 20 years, though sensibly becoming less valuable, land has remained still worth two or three times the rent it paid before the bones were laid on.

It is this lengthened good effect of bone-dust that affords the strongest ground for believing that the earthy phosphate has a large share in the effect. I have already shown that this prolonged action is not conclusive upon the point—since the organic matter lingers long, even in buried bones—but a consideration of the necessary effect of long-continued pasturage upon soils to which nothing is artificially added, lends a singular support to the view that the bone-earth may act an important and beneficial part upon old meadow and other grass lands. Take the instance of a dairy farm in the neighbourhood of a large town,—

1°. The milk is all carried off the farm, either directly or in the shape of butter, cheese, &c., and every 40 gallons of milk contain 1 lb. of bone earth, besides other phosphates. Estimate the average yield of a good cow at 3000 quarts, or 750 gallons a year, its milk will contain 19 lbs.

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* See top of page 228, Part III.

of earthy phosphate—as much as is present in 30 lbs. of bone-dust.

2°. Again, the urine of a *milk* cow, taken at 700 gallons a year, contains about 11 lbs. of the same phosphate.* Suppose only a third of this run to waste, and the farm will lose for every cow in this way about 4 lbs.—equal to about 6 lbs. of bone-dust.

3°. But for every cow an annual calf is reared and sold off. Let this calf contain but 20 lbs. of bone—then *for every cow it maintains, a dairy farm will lose of earthy phosphates upon the whole as much as is contained in 56 lbs. of bone-dust.* Suppose a farm to be pastured for centuries, as those of Cheshire have been, and the produce to be carried off in the form of milk, butter, and veal—we may reasonably suppose that it will at length begin to feel the want of those phosphates which year by year have been drawn from its surface. It is reasonable also to suppose that the addition of these deficient phosphates would impart new vigour to the soil, would cause new grasses to sprout, and a more *milk-yielding* herbage to spring up.

Such is the reasoning upon which I some years ago attempted to found an explanation of the singularly striking effects produced by bone-dust on the grass lands of Cheshire, while it failed materially to improve those of other districts on which it had been tried. I still consider it as by no means without its weight, though I cannot concur with the extreme views which some have since adopted—that either in the case of Cheshire, or in any other case with which I am acquainted, the beneficial action of bone-dust is to be ascribed *solely* to its earthy constituents.

§ 6. *Of animal charcoal, the refuse of the sugar refineries, and animalised carbon.*

1°. *Animal charcoal* (*bone black*).—When bones are charred or distilled at a red heat in close vessels, they leave behind a coaly residuum to which the name of animal charcoal is usually given. By this calcination the animal matter is almost entirely decomposed. The charcoal still retains, however, a little nitrogen, and though it is seldom employed as a manure, yet it is not wholly without effect in promoting the growth of our cultivated crops. Thus in 1842, when applied to Swedish turnips, Mr. Fleming obtained from the unmanured soil 12 tons 5 cwt. per acre; but when manured with 10 cwt. of animal charcoal, 21 tons 2 cwt.*

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* A cow, *not in milk*, gives on an average about 1300 gallons of urine (see Part III., p. 243.)

2°. *Refuse charcoal of the sugar refiners.*—The animal charcoal above described is chiefly employed for the purpose of removing the colour from solutions of raw sugar. Blood is also used for clarifying the same solutions, and quick-lime for neutralizing the acid matter they contain, thus rendering the syrups more capable of easy crystallization. Hence the animal charcoal, the blood, the lime, and the colouring and other matters separated from the sugar, become mixed together, and form the refuse of the sugar refiners. This refuse often contains from one-fifth to one-fourth of its weight of blood, and hence is in general—and especially in France, where it is extensively employed as a manure—considered from four to six times more powerful than the pure animal charcoal alone. In the western parts of France this mixture has for some years been in great repute among agriculturists, and, in addition to that which is produced at home, has been largely imported from other countries. Into the ports upon the river Loire alone there were entered, in 1839, upwards of ten thousand tons.† It sells at about five pounds a ton.

The value of this substance depends very much upon the proportion of blood which it contains, and as this is in some measure variable, its fertilizing qualities must be variable also. In this country blood is used much more sparingly in the refining of sugar than it used to be, and hence the refuse of our refineries is probably less valuable as a manure now than it was in former years.‡ This is probably one reason why Mr. Fleming obtained from the use of it a somewhat smaller crop of turnips than from an equal quantity of the unused animal charcoal. Upon Swedish turnips 10 cwt. of unused animal charcoal gave him 21 tons 2 cwt.; while 10 cwt. of the refuse gave 10 tons 7 cwt.*

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* See *Appendix*.

† Boussingault, *An. de Chim. et de Phys.*, 3d series, iii., p. 96.

‡ The refining "consists in putting the sugar into a large square copper cistern, along with some lime water, a little bullock's blood, and from 5 to 20 per cent. of bone black, and injecting steam through the mixture. *Instead of the blood* many refiners employ a mixture of gelatinous alumina

Still this result is sufficiently favourable to recommend the refuse or exhausted animal charcoal to the practical agriculturist where more economical manures cannot readily be obtained.

3°. *Animalized Carbon.*—The estimation in which the refuse charcoal of the sugar works was held has led to the manufacture of very useful imitations of it under the name of animalized carbon. A calcareous soil, rich in vegetable matter,† is charred in close vessels, and is then mixed at intervals with repeated portions of night soil as long as it disinfects it or removes its smell—and to this mixture is added 4 or 5 per cent. of clotted or partially dried blood. This animalized carbon is said to be of much value as a manure. The main objections to it are its liability to adulteration and the uncertainty to which, even when skilfully and conscientiously prepared, its composition must be in some measure liable.

§ 7. *Of fish, fish refuse, whale blubber, and oil.*

1°. *Fish.*—In some parts of the world, and occasionally on the shores of our own island, fish are met with in such abundance that they can be economically employed as a manure for the land. They are either spread over it in a recent state, or—which is more economical—are made into a compost, chiefly with earth, which, after a time, proves rich and fertilizing.

The bones of fish are similar in composition to those of terrestrial animals (Part III., p. 225), and their muscular

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and gypsum, called *finings*, prepared by adding lime water to a solution of alum, and collecting the precipitate." (Ure). Hence the reason why, in England at least, the refuse charcoal of the sugar works is not *always* rich in blood.

* *Appendix.*

† An intimate mixture of peat and marl or shell-sand would answer well.

parts are nearly identical in elementary constitution with the lean part of beef and the clot of blood. As fertilizing agents, therefore, the parts of fishes will act nearly in the same way as the blood and bodies of animals.

2°. *Fish refuse.*—The pilchards of Cornwall, and the herrings, cod, and ling of our Northern coasts, when cleaned for salting, yield a large quantity of refuse,[*] which is peculiarly valuable to the farmers in the neighbourhood of the principal fishing stations.

In the North, a compost prepared from this fish refuse is generally esteemed as a manure for barley and green crops, but when extensively used, "is said to render the soil unfit for the production of oats." Such soil is said to be poisoned.[†]

3°. *Whale blubber.*—When the oil is expressed from whale blubber, a skinny or membraneous refuse remains, which has hitherto been employed only as a manure. It is made into a compost with earth, which is several times turned, and the mixture is most usefully employed after it has lain not less than 9 or 12 months. It may be applied either to grass or to arable land.

4°. *Whale oil*, and that of other fish, when made into a compost with earth and a little lime or wood ashes, yields a manure which was much recommended by the late Dr. Hunter of York[‡] Merely mixed with absorbent earth, and applied at the end of one month, impure whale oil, at the rate of 40 gallons per acre, gave the late Mr. Mason, of Chilton, near Durham, a crop of 23¼ tons of turnips, while 40 bushels of bones gave him only 22 tons. More recently, also, it has been found that the mixture of a few gallons of oil with the usual quantity of bone-dust increased to a considerable degree the turnip crop to which it was applied. In a theoretical point of view, it would be interesting to establish the fact, that *pure* oil is capable of promoting in a large degree the growth and produce of our cultivated crops—though as a resource, of which farmers in general can avail themselves where other manure is scarce, its high price will probably prevent it from ever becoming extensively useful.

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[*] Fourteen barrels of herrings yield one of refuse.

[†] Sinclair's *Statistical Account of Scotland*, vii., p. 201, quoted in *British Husbandry*, I., p. 421.

[‡] See his *Georgical Essays*, vols. 1, 2 and 5.

§ 8. *Relative fertilizing value of the animal manures already described.*

No sufficiently decisive experiments are yet upon record, from which the relative value of the several animal manures above described can be satisfactorily deduced. That they differ in fertilizing power every farmer is aware, but it is not yet decided by actual trial, in what proportion one of them exceeds the other.

I have already stated to you (Part III., p. 214) the theoretical opinion entertained by many that *the efficacy of all manures is in proportion to the quantity of nitrogen they contain.* Adopting this principle as true, it is easy to assign to each substance its proper place in an artificial table. The last column in the following table shows the quantity of each substance *in its ordinary state of dryness*, which will be necessary to produce the same effect as 100 lbs. of common farm-yard manure, supposing this effect to be determined by the nitrogen alone.

	Water per cent.	Ash per cent.	Nitrogen per cent.	Equal effects produced by
Farm-yard Manure .	80	?	½	100 lbs.
Flesh	77	1	3½	14 .
Fish	80	2	2½	20 ..
Blood	79 to 83	1	3	16 ..
Blood dried*	12 to 20	3½	12 to 13	8 ..
Skin	58	½	8	12 ..
Wool, Hair, and Horn	9 to 11	1 to 2	16	6 ..
Bones	14	40 to 60	5 to 9	11 to 20 ..
Refuse Charcoal of the Sugar works	48	?	1	50
Animalized Carbon .	45	?	1	50

I have already had occasion to remark, however, that this mode of classifying manures is not altogether to be depended upon. Since—

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* As it is sold for manure at Paris and elsewhere, Part III., p. 218.

1°. It does not take into account the quantity of inorganic matter they severally contain, which, as shown in the third column, is particularly large in bones, and is by some considered as the (most?) important and influential constituent of this manure. Nor is any effect ascribed to such substances as the sulphur, which in hair and wool forms nearly 5 per cent. of their whole weight, and which cannot be wholly without influence upon the plants, by which, as they decay, the elements of these manures may happen to be absorbed.

2°. It passes by the *practical* influence of the quantity of water which the several substances contain. Flesh, fish, blood, and skin, in their recent state, contain so much water that they begin almost immediately to decompose, and thus expend most of their fertilizing virtue upon the first crop to which they are applied. Hair and wool, on the other hand, retain so little water that they decay with great slowness. Hence, the true amount of the action of these latter substances cannot be estimated in a single year, and must, therefore, be altogether a matter of theory until a series of careful observations, made in consecutive years, shall afford some decisive facts upon which to reason.

3°. This is confirmed by the statement of Boussingault and Payen,* that the effect of the animal charcoal of the sugar-refiners and of the animalized carbon is, *by experience, five times greater* than the proportion of nitrogen they contain would indicate; and—

4°. If pure oil, which contains no nitrogen at all, will yet produce an enriching manure by mere mixture with the soil (Part III., p. 234), or will increase greatly the effect of bones—we must obviously seek for some other principle upon which to account for the effect of manures, besides or in addition to the proportion of nitrogen they contain. It is true that the *impure* or refuse whale oil used for composts may contain some nitrogen, but we can scarcely suppose 250 or 300 lbs. of such oil to hold so much of this element as to account for all the effects which the oil is said to have produced.

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* *Annales de Chim. et de Phys.*, 3rd series, iii., p. 94.

While, then, we put so much faith in theory as to believe that substances which contain much nitrogen are very likely to prove valuable manures,—we must not allow ourselves to be so carried away by the simplicity of the principle as to believe either that their relative effects upon our crops may be *always* estimated by the proportion of nitrogen they contain, or that a substance may not largely increase the produce of our fields in which no nitrogen is present at all. Indeed the effects of saline substances alone are sufficient to satisfy us how untrue to nature this latter opinion would be.

§ 9. *Of the droppings of fowls—pigeons' dung, and guano.*

The droppings of birds form one of the most powerful of known manures. This arises in part from the circumstance that in the economy of birds there is no final separation between the liquid and solid excretions. Both escape mixed together from the same aperture.

1°. *Pigeons' dung* is much prized as a manure wherever it can be obtained in any considerable quantity. In Belgium it is esteemed as a top-dressing for the young flax, and the yearly produce of 100 pigeons is sold for about 20s. Its immediate effect depends upon the quantity of soluble matter it contains, and this varies much according to its age and to the circumstances under which it has been preserved. Thus Davy* and Sprengel obtained respectively of

	Recent. (Davy.)	Six months old. (Sprengel.)	After fermentation (Davy.)
Soluble matter in pigeons' dung	23 per cent.	16 per cent.	8 per cent.

The soluble matter consists of uric acid in small quantity, of urate, sulphate, and especially of carbonate of ammonia, common salt, and sulphate of potash;—the insoluble chiefly of phosphate of lime, with a little phosphate of magnesia, and a variable admixture of sand and other earthy matters.† When exposed to moisture, the pigeons' dung, especially if recent, undergoes fermentation, loses a portion of its ammoniacal salts, and thus becomes less valuable. When it is intended to be kept it should be mixed with a dry vegetable soil, or made into a compost with earth and saw-dust, with a portion of pulverized or charred peat, or with such a disinfecting charcoal as that which is employed in the manufacture of the animalized carbon above described.

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* Davy's *Agricultural Chemistry*, Lecture VI.

† Sprengel's *Lehre vom Dünger*, p. 140.

2°. *Hens' dung* often accumulates, decomposes, and runs to waste in poultry yards, when, with a little care, it might be collected in considerable quantities.

3°. *Goose dung* is less rich than that of hens or pigeons, because this bird feeds less upon grain, and derives a considerable portion of its nourishment from the grass which it crops, when allowed to go at liberty over the fields. Its known injurious effects upon the grass on which it falls arise from its being in too concentrated a state. In moist weather, or where rain soon succeeds, it does no injury, and even when in dry weather it kills the blades on which it drops, it brings up the succeeding shoots with increased luxuriance.

4°. *Rooks' dung* unites with the leaves of the trees among which they live, in enriching the pasture beneath them. In old rookeries the soil is observed also to be slowly elevated above the surrounding land. This surface soil I have found to be especially rich in phosphate of lime, which has gradually accumulated and remained in it while the volatile and soluble parts of the droppings of the birds have slowly disappeared.

5°. *Guano* is the name given to the accumulated dung chiefly of sea birds, which is found upon the rocky promontories, and on the islands that skirt the coast of South America, from the 13th to the 21st degree of south latitude. In that part of America, the climate being very dry, the droppings of the birds have decomposed with exceeding slowness, and upon some spots have continued to accumulate for many centuries, forming layers, more or less extensive, of 10, 20, and at certain places it is said even 60 (?) feet in thickness. In some places the more ancient of these deposits are covered by layers of drift sand, which tend further to preserve them from decay. In our moist climate the dung of the sea fowl is readily washed away by the rains, so that even where sea birds most abound no considerable quantity of guano can ever be expected to collect.

The solid part of the droppings of birds in general, when recent, consists chiefly of uric acid, with a little urate of ammonia, and a variable per-centage of phosphate of lime and other saline compounds. The liquid part, like the urine of other animals, contains much urea, with some phosphates, sulphates, and chlorides. The uric acid and urea, however, gradually undergo decomposition, and are changed into carbonate and other salts of ammonia. If applied to the land when this stage of decomposition is attained, they form an active, powerful, and immediately operating manure; but if allowed to remain exposed to the air for a lengthened period of time, the salts of ammonia gradually volatilize, and the efficacy of what remains becómes greatly diminished. Hence the guano which is imported into this country is very variable in quality, some samples being capable of yielding only 7 per cent. of ammonia, while others are said to give as much as 25 per cent. Of two portions taken by myself from the same box, the one contained 8 per cent. and the other only 1½ per cent. of sand, while their other constituents were as follows:—

1°.	per cent.
Water, salts of ammonia, and organic matter expelled by a red heat .	23·5
Sulphate of soda . . .	1·8
Common salt, with a little phosphate of soda .	30·3
Phosphate of lime, with a little phosphate of magnesia and carbonate of lime	44·4
	100

2°.	per cent
Ammonia	7·0
Uric acid	0·8
Water and carbonic and oxalic acids, &c., expelled by red heat .	51·5
Common salt, with a little sulphate and phosphate of soda . . .	11·4
Phosphate of lime, . .	29·3
	100

On the other hand, Dr. Ure gives the following as the *average* result of his analyses of genuine guano:—

	per cent
Organic matter containing nitrogen, including urate of ammonia, and capable of affording from 8 to 17 per cent. of ammonia by slow decomposition in the soil . . .	50
Water	11
Phosphate of lime	25
Ammonia, phosphate of magnesia, phosphate of ammonia, and oxalate of ammonia, containing from 4 to 9 per cent. of ammonia	13
Siliceous matter from the crops of the birds . . .	1
	100[*]

Others have found sand in much larger proportion than was present in the samples examined by myself—while it may, I think, be taken for granted, that very little of what comes to this country is so rich in soluble matter, containing ammonia or its elements, as is represented by the analysis of Dr. Ure.[†]

Variable as its composition is, however, there is now no doubt that any of the samples yet brought into the English market may be advantageously applied as a manure to almost any crop. From the most remote period guano has been the chief manure applied to the land on the parched shores of Peru—and at the present day it is not only employed for the same purpose in the provinces which lie along the coast, but it is also carried across the desert of Atacama many leagues inland, "on the backs of mules over rough mountain paths, and at a great expense, for the use of the agricultural districts of Peru and Bolivia."[‡] It has been estimated that a hundred thou-

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[*] By way of comparison, I insert here the approximate composition of the solid part of the excrements of four different varieties of eagle, as determined by Coindet :—

	Senegal Eagle.	American Hunting Eagle.	American Fishing Eagle.	Grand Duke of Verginia.
Uric acid . . .	89·79	90·37	84·65	88·71
Ammonia . . .	7·85	8·87	9·20	8·55
Phosphate of lime	2·36	0·76	6·15	2·74
	100	100	100	100 (a)

[†] The presence of ammonia in guano is readily ascertained by mixing it with a little slaked lime—when the odour of ammonia will be immediately perceived, and will be strong in proportion to the quantity contained in the guano.

[‡] Silliman's *Journal*, xliv., p. 10.

(a) Gmelin *Handbuch der Chemie*, II., p. 1456.

sand quintals* are, at the present day, annually sold in Peru. There also the quality and the price vary—the recent white guano selling usually at 3s. 6d., the more recent red and gray varieties at 2s. 3d. per cwt. (Winterfeldt.)† In this country the latter—the only variety yet imported—sells at present (1843), at about 10s. a cwt.

In regard to the effects of guano upon various crops many important experimental results, obtained in 1842, will be found in the Appendix. I here insert a few of the more important of these, along with some others made in the more southern counties, which appear to be highly deserving of consideration.

Swedish Turnips.

	Top-dressed with			Produce per Acre. tons.	cwt.	Locality.
1°.	Farm-yard dung	20	tons.	18	11	Barochan, near Paisley.
	Guano . .	3	cwt.	23	8	
2°.	Farm-yard dung	20	tons.	16	18	Parish of Wraxall, Somerset.
	Guano‡ . .	2¼	cwt.	17	4	
	Bones . .	32	bush.	15	17	
	Yellow Turnips.					
	Guano§ . .	5	cwt.	32	2	Barochan, near Paisley.
	Rape-dust .	15	cwt.	24	11	
	Bone-dust .	30	bush.	17	2	
	Potatoes.					
1°.	Guano . .	3	cwt.	18	9	Barochan. In all these cases the manures were put in *alone* with the potato cuttings, no other manure being afterwards added.
	Rape-dust .	1	ton.	12	6	
2°.	Guano . .	4	cwt.	14	6	
	Rape-dust .	1	ton.	10	0	
	Bone-dust .	45	bush.	9	15	
3°.	Guano . :	4	cwt.	13	14	
	Rape-dust .	1	ton.	13	0	
	Bone-dust .	45	bush.	13	14	

As a top-dressing to the young potato crop at Erskine in 1842, one cwt. of guano per acre produced no important increase. This might, however, be owing to the extreme dryness of the season (see Appendix).

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* The quintal is equal to 101¼ lbs. avoirdupois.

† For further particulars regarding guano the reader is referred to a paper in the *Journal of the Royal Agricultural Society*, II., p. 301.

‡ Mixed with 1 cwt. of charcoal powder.

§ Mixed with 20 bushels of wood-ashes.

Wheat.

	Top-dressed with		Produce per Acre. tons.	cwt.	Locality.
1°.	Guano	1 cwt.	48	0	Lennox Love, near Haddington—drought very great.
	Rape-dust	16 cwt.	51	0	
	Undressed	-	47½	0	
2°.	Guano	3 cwt.	30	40	Barochan.
	Undressed	-	24	57	
3°.	Guano	2 cwt.	32	20	Gardgirth, near Ayr.
	Undressed*	-	31	31	
4°.	Guano	1 cwt.	46	15	Erskine, Renfrewshire.†
	Nitrate of soda	2 cwt.	54	18	
	Undressed	-	44	4	
5°.	Guano	1¼ cwt.	45	0	Seisdon, Worcestershire.‡
	Nitrate of soda	1¼ cwt.	41	0	
	Undressed	-	39	0	

Barley.

	Guano	3 cwt.	64	0	Barochan.
	Undressed	-	47	15	

Oats.

1°.	Guano	2 cwt.	70	0	Lennox Love, near Haddington.
	Undressed	-	52	0	
2°.	Guano	1 cwt.	48	16	Erskine, Renfrewshire.
	Nitrate of soda	1 cwt.	50	0	
	Undressed	-	49	0	

Beans.

			bush.		
	Guano	2 cwt.	33½		Lennox Love, near Haddington.
	Rape-dust	16 cwt.	35		
	Nitrate of soda	1 cwt.	33		
	Undressed	-	29¾		

Hay.

			tons.	cwt.	
1°.	Guano	1½ cwt.	1	18	Barochan, near Paisley.
	Nitrate of soda	1½ cwt.	2	10	
	Undressed	-	1	8	
2°.	Guano	1½ cwt.	2	2	Erskine, Renfrewshire.
	Nitrate of soda	1½ cwt.	1	17	
	Undressed	-	1	10	

* The undressed grain was of superior quality, yielding 76¼ per cent. of fine flour, while that dressed with guano gave only 68¾ per cent.

† The grain dressed with guano weighed half a pound per bushel less than the others.

‡ The guano gave 4 cwt. more straw than the nitrate, and 11 cwt. more than the undressed. The undressed grain also weighed half a pound less per bushel than either of the other two.

An inspection of the above results appear to indicate that guano is more *uniformly* successful with root crops, than when applied as a top-dressing to corn and grass. The unusual drought which prevailed in 1842 no doubt materially diminished its action, when used as a top-dressing—and the results upon the corn crops in a more moist season may probably prove more generally favourable to its use as an economical manure.

Some experiments seem already to indicate that the favourable influence of guano does not cease with the first season. If the phosphate of lime which they contain operate in any way in prolonging the fertilizing operation of bones, the large, though variable, quantity of this phosphate contained in guano should render this latter substance also capable of permanently improving the soil.

By exposure to the air, guano gradually gives off a portion of its volatile constituents; it ought, therefore, to be kept in covered vessels or casks. It also in our climate absorbs moisture from the air, and therefore should be purchased as soon as possible after importation. When applied as a top-dressing it may be conveniently mixed with an equal weight of gypsum or wood-ashes—with charcoal powder, or with fine dry soil.

§ 10. *Of liquid animal manures—the urine of man, of the cow, the horse, the sheep, and the pig.*

Of natural liquid manures, the most important and valuable, though the most neglected and the most wasted also, consist of the urine of man and of the animals he has domesticated.

The efficacy of urine as a manure depends upon the quantity of solid matter which it holds in solution, upon the nature of this solid matter, and especially upon the rapid changes which the organic part of it is known to undergo. The following table exhibits the average proportions of water, and of the solid organic and inorganic matters contained in the urine of man and some other animals in their healthy state—and the average quantity voided by each in a day :—

Urine of	Water in 1000 parts.	Solid matter in 1000 parts.			Aver. quantity voided in 24 hours.
		Organic.	Inorganic.	Total.	
Man	969*	23·4	7·6	31	3 lbs.
Horse	940	27	33	60	3 "
Cow	930	50	20	70	40† "
Pig	926	56	18	74	?
Sheep	960	28	12	40	?

The numbers in the above table show that the urine of the cow, estimated by the quantity of solid matter it contains, is more valuable than that of any other of our domestic animals, with the exception of the pig. But the quantity voided by the cow must be so much greater than by the pig, that in annual value the urine of one cow must greatly exceed that of many pigs.

It might be supposed at first that in all animals the quantity of urine voided would have a close connection with the quantity of water which each was in the habit of drinking. But this is by no means the case. Thus it is the result of experiment that in man the drink exceeds the urine voided by *about one-tenth part only*—while

Of water in 24 hours. Of urine in 24 hours.
A horse, which drank 35 lbs., gave only 3 lbs.
A cow, which drank 132 lbs., gave 18 lbs., and
19 lbs. of milk (Boussingault).

How very large a quantity of the liquid they drink must escape from the horse and the cow in the form of insensible perspiration! That this should be very much greater indeed than in man, we are prepared to expect from the greater extent of surface which the bodies of these animals present.

Let us now examine more closely the composition of urine, the changes which by decomposition it readily undergoes, and the effect of these changes upon its value as a manure.

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[*] Alfred Becquerel. See Thomson's *Animal Chemistry*, p. 477. It is to be observed that the proportions of water and of solid matter in urine vary with the food, and with a great variety of circumstances.

[†] A *milk* cow voids less than this in a proportion which varies with the quantity of milk she gives. Boussingault found a milk cow to yield daily 18 lbs. of urine and 19 lbs of milk.—*Ann. de Chym. et de Phys.*, lxxi., pp. 123, 124.

1°. *Human urine.*—The exact composition of the urine of a healthy individual in its usual state was found by Berzelius to be as follows:—

Water - - -	933·0	Phosphate of ammonia -	1·6
Urea - - - -	30·1	Common salt - -	4·5
Uric acid - - -	1·0	Sal-ammoniac - -	1·5
Free lactic acid, lactate of ammonia, & animal matter not separable -	17·1	Phosphates of lime and magnesia, with a trace of silica and of fluoride of calcium - - -	1·1
Mucus of the bladder -	0·3		
Sulphate of potash -	3·7		
Sulphate of soda - -	3·2		1000
Phosphate of soda -	2·9		

From what I have already had occasion to state in regard to the action upon living plants, of the several sulphates, phosphates, and other saline compounds, mentioned in the above analysis, you will see that the fertilizing action of urine would be considerable, did it contain no other solid constituents. But it is to the urea which exists in it in very much larger quantity than any other substance, that its immediate and marked action in promoting vegetation is chiefly to be ascribed. This urea which is a white salt-like substance consists of—

	per cent.
Carbon - - - - - -	20·0
Hydrogen - - - - -	6·6
Nitrogen - - - - -	46·7
Oxygen - - - - - -	26·7
	100

It is, therefore, far richer in nitrogen than flesh, blood, or any of those other richly fertilizing substances, of which the main efficacy is supposed to depend upon the large proportion of nitrogen they contain.

But urea possesses this further remarkable property, that when urine begins to ferment,—as it is known to do in a few days after it is voided—it changes entirely into carbonate of ammonia.* Of the ammonia thus formed a portion soon begins to escape into the air, and hence the strong ammoniacal odour of fermenting urine. This escape of ammonia continues for a long period, the liquid becoming weaker and weaker, and consequently less valuable as a manure every day that passes. Experience has shown that recent urine exercises in general an unfavourable action upon growing plants, and that it acts most beneficially after fermentation has freely begun, but the longer time we suffer to elapse after it has reached the *ripe* state, the greater the quantity of valuable manure we permit to go to waste.

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* This takes place by the decomposition at the same time of two atoms of the water in which it is dissolved. Thus urea is represented by

2°. *The urine of the cow* has been analysed in several states by Sprengel, with the following results in 1000 parts:—

	Fresh.	Allowed to ferment for four weeks in the open air.	
		A.	B.
Water	926·2	954·4	934·8
Urea	40·0	10·0	6·0
Mucus	2·0	0·4	0·3
Hippuric and lactic acids	6·1	7·5	6·2
Carbonic acid	2·6	1·7	15·3
Ammonia	2·1	4·9	16·2
Potash	6·6	6·6	6·6
Soda	5·5	5·5	5·6
Sulphuric acid	4·0	3·9	3·3
Phosphoric acid	0·7	0·3	1·5
Chlorine	2·7	2·7	2·7
Lime	0·6	trace	trace
Magnesia	0·4	0·2	0·4
Alumina, oxide of iron, and oxide of manganese	0·1	trace	—
Silica	0·4	0·1	0·1
	1000	998·2	999·0*

$C_2H_4N_2O_2$; two of water by $2\,HO$; and carbonate of ammonia by NH_3+CO_2; and the change is thus shown—

$$\overset{\text{Urea.}}{C_2H_4N_2O_2} + \overset{\text{2 of Water}}{2\,H\,O} = \overset{\text{2 of Carbonate of Ammonia.}}{2\,(N\,H_3 + C\,O_2.)}$$

[*] The small quantity necessary to make up the 1000 parts in the two latter analyses consisted of a deposit of carbonate and phosphate of lime and other earthy matters which had gradually been formed, and of a trace of vinegar and of sulphuretted hydrogen.—See Sprengel, *Lehre vom Dünger*, pp. 107 to 110.

The first variety of fermented urine (A.), had stood four weeks in the air in its natural state of dilution; the second (B.), had been mixed while recent with an equal bulk of water—which is again deducted from it in the analysis—with the view of ascertaining how far such an admixture would tend to retain the volatile ammonia produced by the natural decomposition of the urea.

An inspection of these tables shows three facts of importance to the agriculturist—

1°. That the quantity of urea in the urine of the cow is considerably greater than in that of man. 2°. That as the urine ferments the quantity of urea diminishes, while that of ammonia increases—owing, as I have already stated, to the gradual decomposition of the urea, and its conversion into carbonate of ammonia; and, 3°. That by dilution with an equal bulk of water the loss of this carbonate of ammonia, which would otherwise naturally take place, is in a considerable degree prevented. *The quantity of ammonia retained by the urine, after dilution, was in the same circumstances nearly three times as great as when it was allowed to ferment in the state in which it came from the cow.*

But even by this dilution the whole of the ammonia is not saved. One hundred parts of urea form by their decomposition 56½ parts of ammonia, and as 36 parts of the urea in the urine B. had disappeared, there ought to have been in its stead 19 parts of ammonia in addition to that which the urine contained in its recent state, or 21 parts in all—whereas the table shows it to have contained only 16 parts. Even when diluted with its own bulk of water, therefore, the urine had lost by fermentation in the open air upwards of one-fourth of the ammonia produced in it during that period. This shows the necessity of causing our liquid manures to ferment in covered cisterns, or of adopting some other means by which the above serious loss of the most valuable constituents may be prevented.

3°. *The urine of the horse, sheep, and pig* have not been so carefully analyzed as that of the cow. They consist essentially of the same constituents, and the specimens which have been examined were found to contain the three most important of these in the following proportions:—

	Horse.		Sheep.		Pig.
Water - -	940	..	960	..	926
Urea - -	7?	..	28	..	56
Saline substances	53	..	12	..	18
	1000		1000		1000

Some of the saline substances present in the urine, as above stated, contain nitrogen. This is especially the case in the urine of the horse, so that the quantity of urea above given is not to be considered as representing the true ammonia-producing power of the urine of this animal. The urine of the pig, if the above analysis is to be relied upon as any thing like an average result, is capable of producing more ammonia from the same quantity than that of any other of our domestic animals.

§ 11. *Of the waste of liquid manure—of urate, and of sulphated urine.*

1°. *Waste of human urine.*—The quantity of solid matter contained in the *recent* urine voided in a year by a man, a horse, and a cow, and the weight of ammonia they are respectively capable of yielding, may be represented as follows:—

	Quantity of urine.	Solid matter.	Containing of urea.	And yielding of ammonia.
Man -	1,000 lbs	67 lbs	30 lbs.	17 lbs.
Horse -	1,000	60	?	?
Cow -	13,000	900	400	230*

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* The numbers given above, and in p. 244, are calculated from the analysis of the urine of the horse by *Fourcroy* and *Vauquelin*, and of that of the cow by *Sprengel*. Boussingault, however, obtained very different results. Thus a cow and a horse, on which his experiments were made, yielded a quantity of urine which in a year would have amounted to, and would have contained, *in pounds*—

	Quantity.	Containing of Solid matter (total.)	Inorganic matter.	Nitrogen.	Capable of yielding of ammonia.
Cow -	6570	773	309	29	35
Horse -	1100	243	89	30	36

The cow yielded, at the same time, 19 lbs. of milk each day, which accounts for the smaller proportion of urine voided than is given in the text. It is remarkable, however, that the quantity of nitrogen contained in an

How much of all this enriching matter is permitted to run to waste? The solid substances contained in urine, if all added to the land, would be more fertilizing than guano, which now sells at £10 a ton. If we estimate the urine of each individual on an average at only 600 lbs., then there are carried into the common sewers of a city of 15,000 inhabitants, a yearly weight of 600 thousand pounds, or 270 tons, of manure, which, at the present price of guano, is worth £2700—which would, no doubt, prove more fertilizing than its own weight of guano, and might be expected to raise an increased produce of not less than 1000 quarters of grain.

The saving of all this manure would be a great national benefit, though it is not easy to see by what means it could be effectually accomplished. What is thus carried off by the sewers, and conveyed ultimately to the sea, is drawn from and lost by the land, which must, therefore, to a certain extent, be impoverished. Can we believe that in the form of fish, of sea-tangle, or of spray, the sea ever delivers back a tithe of the enriching matter it daily receives from the land?

2°. *Urate.*—In order to prevent a portion of this waste, the practice has been introduced into some large cities of collecting the urine, adding to it one-seventh of its weight of powdered gypsum, allowing the whole to stand for some days, pouring off the liquid and drying the powder. Under the name of *urate* this dry powder has been highly extolled, but it can contain only a small portion of what is really valuable in urine. The liquid portion poured off must contain most of the soluble ammoniacal and other salts, and even were the whole evaporated to dryness, the

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equal weight of the urine of the horse was in this case so much greater than in that of the cow—and that the whole amount which would have been yielded by that of the cow in a year should be so very much less than in the result obtained by Sprengel. The milk did not contain nitrogen sufficient to yield more than 45 lbs. of ammonia, and this, added to the 35 lbs. from the urine, makes only 80 lbs. in all—whereas Sprengel gives 230 lbs. as the quantity which recent urine is capable of yielding. This remarkable difference must be ascribed either to an actual loss of volatile matter by the urine analyzed by Boussingault, or—which is more probable—to a difference in the quality of the food on which the two animals were fed.

gypsum does not act so rapidly in fixing the ammonia as to prevent a considerable escape of this compound as the fermentation of the urine proceeds.

3°. *Sulphated urine.*—A method of more apparent promise is that now practised by the Messrs. Turnbull, of Glasgow, of adding diluted sulphuric acid to the urine as the ammonia is formed in it, and subsequently evaporating the whole to dryness. From the use of this substance very favourable results may be anticipated.* Still none of these preparations will ever equal the urine itself, part of the efficacy of which depends upon the perfect state of solution in which all the substances it contains exist, and upon the readiness with which in this state they make their way into the roots of plants.

4°. *Loss of cows' urine.*—When left to ferment for five or six weeks alone, and with the addition of an equal bulk of water, the urine of the cow loses, as we have seen, a considerable proportion of volatile matter, and in these several states will yield in a year—

	Solid matter.	Yielding of ammonia.
Recent urine - -	900 lbs.	226 lbs.
Mixed with water, after 6 weeks	850 ..	200 ..
Unmixed, after 6 weeks -	550 ..	30 ..

Those who scrupulously collect in tanks, and preserve the liquid manure of their stables, cow-houses and, fold-yards, will see, from the great loss which it undergoes by natural fermentation, the propriety of occasionally washing out their cow-houses with water, and by thus diluting the liquid of their tanks, of preserving the immediately operating constituents of their liquid manure from escaping into the air. Even when thus diluted it is desirable to convey it on to the land without much loss of time, since even in this state there is a constant slow escape, by which its value is daily diminished. Gypsum, sulphate of iron, and sulphuric acid are, by some, added for the purpose of *fixing* the ammonia, but in addition to diluting it, an admixture of rich vegetable soil, and especially of peat, will be much more economical, and, except in so far as the gypsum or sulphuric acid themselves act as manures, nearly as effectual.

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* The Messrs. Turnbull inform me that with this *sulphated urine*, under the incorrect name of *sulphate of ammonia*, the experiments of Mr. Burnet were made (Part III., p. 92), as well as those of Mr. Fleming and Mr. Alexander, detailed in the Appendix.

But these remarks apply only to the liquid manure when collected. How much larger a waste is incurred by those who make no effort to collect the urine of their cow-houses or stables! The recent urine of one cow is valued in Flanders, where liquid manures are highly esteemed, at 40s. a year. It contains on an average, as we have seen, 900 lbs. of solid matter, and this, estimated at the price of guano only, is worth at present £4 sterling. Multiply this by eight millions, the number of cattle said to exist in the United Kingdom, and we have 32 millions of pounds sterling, as the value of the urine, supposing it to be worth no more than the foreign guano. It is impossible to estimate how much of this runs to waste, but one-tenth of it will amount to nearly as much as the whole income-tax recently laid upon the country. The practical farmer who uses every effort to collect and preserve the manure which nature puts within his reach, is deserving of praise when he expends his money in the purchase of manures brought from a distance, of whatever kind they may be; but he, on the other hand, is only open to censure who puts forward the purchase of foreign manures as an excuse for the neglect of those which are running to waste around him. Let every stock farmer, with the help of the facts above stated, make a fair calculation of what is lost to himself and to the country by the hitherto unheeded waste of the urine of his cattle, and he will be able clearly to appreciate the importance of taking some steps for preseving it in future.

§ 12. *Of solid animal manures—night soil, the dung of the cow, the horse, the sheep, and the pig.*

1°. *Night soil* is in general an exceedingly rich and valuable manure, but its disagreeable odour has in most countries rendered its use unpopular among practical men. This unpleasant smell may be in a great measure removed by mixing it with powdered charcoal or with half-charred peat, a method which is adopted in the manufacture of certain artificial manures. Quick-lime is in some places employed for the same purpose, but though the smell is thus got rid of, a large portion of the volatile ammonia produced during the decomposition of the manure is at the same time driven off by the lime.

In general, night soil contains about three-fourths of its weight of water, and when exposed to the air undergoes a very rapid decomposition, gives off much volatile matter, consisting of ammonia, of carbonic acid, and of sulphuretted and phosphuretted hydrogen gases, and finally loses its smell. In the neighbourhood of many large cities the collected night soil is allowed thus naturally to ferment and lose its smell, and is then dried and sold for manure, under the name of *poudrette.*

But by this fermentation a very large proportion of valuable matter is permitted to escape into the air. To retain this, gypsum or dilute sulphuric acid may be added to the night soil, but the more economical and generally practicable method is to mix it with earth rich in vegetable matter, with partially dried peat, with saw-dust, or with some other readily accessible absorbent substance. In this way a rich and fertilizing compost will be obtained, which will have little smell, and yet will retain most of the virtues of the original manure.

In China, the fresh night soil is mixed up with clay and formed into cakes, which when dried are sold under the name of *Taffo*, and form an extensive article of commerce in the neighbourhood of the larger cities.

The composition of night soil, and consequently its value as a manure, varies with the food, and with many other circumstances (Part III., p. 259.) The excrements of a healthy man were found by Berzelius to consist of—

Water	733
Albumen	9
Bile	9
Mucilage, fat, and other animal matters	167
Saline matter	12
Undecomposed food	70
	1000

Of the excrement when freed from water 1000 parts left 132 of ash, consisting of—

Carbonate of Soda	8
Sulphate of Soda, with a little Sulphate of Potash, and Phosphate of Soda	8
Phosphate of Lime and Magnesia, and a trace of Gypsum	100
Silica	16
	132

2°. *Cow dung* forms by far the largest proportion of the animal manure which in modern agriculture is at the disposal of the practical farmer. It ferments more slowly than night soil, or than the dung of the horse and the sheep. In fermenting it does not heat much, and it gives off little of an unpleasant or ammoniacal odour. Hence it acts more slowly, though for a longer period, when applied to the soil.

The slowness of the fermentation arises chiefly from the smaller quantity of nitrogen, or of substances containing nitrogen, which are present in cow dung, but in part also from the food swallowed by the cow being less perfectly masticated than that of man or of the horse. It is a consequence of this slower fermentation that the same evolution of ammoniacal vapours is not perceived from the droppings of the cow as from night soil and from horse dung. Yet by exposure to the air, it undergoes a sensible loss, which in 40 days has been found to amount to five per cent. or nearly one-fifth of the whole solid matter which recent cow-dung contains.* (Gazzeri.) Although, therefore, the comparatively slow fermentation as well as the softness of cow dung fits it better for treading among the straw in the open farm-yard, yet the serious loss which it ultimately undergoes will satisfy the economical farmer that the more effectually he can keep it covered up, or the sooner he can gather his mixed dung and straw into heaps, the greater proportion of this valuable manure will he retain for the future enriching of his fields.

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* Cow dung consisting of 75 of water and 25 of dry solid matter, of which latter 5 disappear.

3°. *Horse-dung* is of a warmer nature than that of the cow. It heats sooner, and evolves much ammonia, not merely because it contains less water than cow dung, but because it is *generally* also richer, in those organic compounds of which nitrogen forms a constituent part. Even when fed upon the same food the dung of the horse will be richer than that of the cow, because of the greater proportion of the food of the latter which is discharged in the large quantity of urine it is in the habit of voiding (Part III., p. 259.)

In the short period of 24 hours horse-dung heats and begins to suffer loss by fermentation. If left in a heap for two or three weeks scarcely seven-tenths of its original weight will remain. Hence the propriety of early removing it from the stable, and of mixing it as soon as possible with some other material by which the volatile substances given off may be absorbed and arrested. The colder and wetter cow or pig's dung will answer well for this purpose, or soil rich in vegetable matter, or peat or sawdust, or powdered charcoal, or any other absorbent substance which can readily be obtained—or if a chemical agent be preferred, moistened gypsum may be sprinkled among it, or diluted sulphuric acid. There is undoubtedly great loss experienced from the general neglect of night soil, but in most cases the dung of the horse might also be rendered a source of much greater profit than it has hitherto been.

The warmth of horse dung fits it admirably for bringing other substances into fermentation. With peat or sawdust it will form a rich compost, and to soils which contain much inert vegetable matter it can be applied with great advantage. Horse and cow dung, in the dry state, have been subjected to ultimate analysis by Boussingault,* with the following results:—

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* *Annales de Chim. et de Phys.* lxv., pp. 122 and 134.

	Dung of the Horse.	Dung of a Milk Cow.
Carbon - - -	38·7	42·8
Hydrogen - - -	5·1	5·2
Oxygen - - -	37·7	37·7
Nitrogen - - -	2·2	2·3
Ashes - - -	16·3	12·0
	100	100
Water* - -	300	566
	400	666

The proportion of nitrogen contained in the two manures, according to these results is so nearly alike—being in reality greater in the cow dung—that were we to consider the above numbers to represent the *average* constitution of the droppings of the horse and cow, we should be compelled to ascribe the difference in their qualities solely to the different states in which the elements exist in the two, and to the proportions of water they respectively contain. But the nature of the food and other circumstances affect the quality of these manures so much (Part III., p. 259,) that we cannot as yet draw any general conclusion from the results obtained in one special case.

1°. *Pig's dung* is still colder and less fermentable than that of the cow. It is characterized by an exceedingly unpleasant odour, which when applied to the land alone it imparts to the crops, and especially to the root crops which are manured with it. Even tobacco, when manured with pig's dung, is said to be so much tainted that the leaves subsequently collected are unfit for smoking.† It is a good manure for hemp and other crops not intended for food, but is best employed in a state of mixture with the other manures of the farm-yard.

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* Recent horse dung losing 75 per cent. of water by drying, of cow dung 75 per cent.

† Sprengel, *Lehre vom Dünger*, p. 38.

5°. *Sheep's dung* is a rich dry manure which ferments more readily than that of the cow, but less so than that of the horse. A specimen examined by Zierl consisted of—

Water - - - - - - -	68·0	per cent.
Animal and vegetable matter - -	19·3	..
Saline matter, or ash - - -	12·7	..
	100	

The food of the sheep is more finely masticated than that of the cow, and its dung contains a little less water, and is probably richer in nitrogen; hence its more rapid fermentation. When crops are eaten off by sheep, their manure is more evenly spread over the field, and is, at the same time, trodden in. When thus spread it decomposes more slowly than when it is collected into heaps, and the ammonia and other useful products of the decomposition are absorbed in great part by the soil as they are produced. Those soils, in which a considerable quantity of vegetable matter is already present, are said to be most benefitted by sheep's dung, because of the readiness with which they absorb the volatile matters it so soon begins to give off.

Sheep's dung is said to lengthen the straw of the corn crops, and to produce a grain rich in gluten—and unfit therefore for seed, for the manufacture of starch, or for the purposes of the brewer and the distiller (Sprengel). It may be doubted, however, whether these can as yet be safely considered as the universal effects of sheep's dung upon every soil, and when the animals are fed upon every kind of food.

§ 13. *Of the quantity of manure produced from the same kinds of food by the horse, the cow, and the sheep.*

The carefully conducted experiments of Block give the following as the total quantities of manure, solid and liquid, produced from 100 lbs. of the different kinds of food by the cow, the horse, and the sheep :—

From 100 lbs. of	Quantity of manure in lbs., produced by						Water in the manure, per cent.
	the Cow.		the Horse.		the Sheep.		
	fresh.	dried.	fresh.	dried.	fresh.	dried.	
Rye -	—	—	212	53	—	—	75
Oats -	—	—	204	51	—	—	75
Rye and other straws (chopped)	268	43	168	42	117	40	66 to 84
Hay -	275	44	172	43	123	42	do. do.
Potatoes (containing 72 per cent. of water)	87½	14	—	—	—	13	do. do.
Turnips (containing 75 per cent. of water)	37½	6	—	—	—	—	84
Carrots (87 per cent. of water	37½	6	—	—	—	—	84
Green Clover (79 pr. ct. of water)	65¾	9⅕	—	—	—	—	86
	after 8 days.		aft. 3 weeks.		aft. 8 weeks.		
Rye Straw (used for bedding)	228	69	269	97	206	95	54 to 64

One important theoretical result is presented by this table—*that the manure voided by an animal contains very much less solid matter than the food it has consumed.* We shall presently see how this fact is to be explained (Part III., p. 262), and, at the same time, what light it throws upon the *quality* of the manure produced.

The most valuable practical results from the above experiments are—

1°. That for 100 lbs. of dry fodder the horse or the cow will give on an average 216 lbs. of fresh, or 46 lbs. of dry manure—the sheep 128 lbs. moist or 43 lbs dry.

2°. That root crops, on an average, give about half their weight of fresh, or one-twelfth of dry manure—the potato giving more and the turnip less.

3°. That green crops give about half their weight of fresh or one-eighth of dry manure.

§ 14. *Of the relative fertilizing values of different animal excretions.*

1°. The theoretical value of different animal excretions calculated *solely* from the quantity of nitrogen which the specimens examined were found respectively to contain, is thus given by Payen and Boussingault. The numbers opposite to each substance indicate the weights of that substance which ought to produce an equal effect with 100 lbs. of farm-yard manure in the recent and in the dry states:

	Equal effects ought to be produced by	
	in the dry state.	artificial dried.
Farm-yard dung	100 lbs.	100 lbs.
Cow	125 ..	84 ..
Do. urine	91 ..	51 ..
Horse	74 ..	88 ..
Mixed excrements of the		
Pig	63 ..	58 ..
Horse	54 ..	64 ..
Sheep	36 ..	65 ..
Pigeon	5 ..	22 ..
Poudrette	10½ ..	44 ..
Another variety	26 ..	73 ..

Too much reliance is not in any case to be placed upon the principle of classifying manures solely by the proportion of nitrogen they contain (Part III, p. 215 & 235)—much less can we depend upon the order of value it assigns to substances, the composition of which is liable to constant change from the escape of those volatile compounds in which the nitrogen principally exists.

2°. A series of experiments made by Hermbstädt upon the quantity of rain of different kinds, raised in the same circumstances by equal weights of different manures, gave the following results:—

	Number of seeds reaped from			
Manure applied.	Wheat.	Barley.	Oats.	Rye.
Ox blood	14	16	12½	14
Night soil	—	13	14½	13½
Sheep's dung	12	16	14	13
Human urine	—	13½	13	13
Horse dung	10	13	14	11
Pigeon dung	—	10	12	9
Cow dung	7	11	16	9
Vegetable matter	3	7	13	6
Unmanured	—	4	5	4

If the results contained in this table were to be depended upon, it would appear that, in so far as the *quantity* of the produce is concerned, these manures severally exercise a special action upon certain crops—that night soil, for example, is most propitious to rye, cow dung to oats, and sheep's dung to barley and wheat. And the latter fact would seem at once to justify and to recommend the eating off with sheep preparatory to either of the latter crops.

None of these kinds of manure, however, is constant in composition, and the following observations will satisfy you that implicit reliance ought not to be placed either upon the relative practical values of the different animal manures as they appear in the latter table, nor on their theoretical values as exhibited in the former.

§ 15. *Influence of circumstances on the* QUALITY *of animal manures.*

The *quality* of the droppings of animals considered as manures is affected by a great variety of circumstances—such as

1°. *By the kind of food upon which the animal is fed.*—Thus night soil is more valuable in those countries and districts in which much flesh meat is consumed, than where vegetable food forms the principal diet of the people. It is even said by Sprengel, that in the neighbourhood of Hildesheim, the farmers give a higher price for the house manure of the Lutheran than for that of the Roman Catholic families, because of the numerous fasts which the latter are required to observe.* Every keeper of stock also knows that the manure in the farm-yard is richer when he is feeding his cattle upon oil-cake, than when he gives them only the ordinary produce of his farm.†

2°. *By the quantity of urine voided by the animal.*—Upon the unlike quantities of urine they produce appears mainly to depend the unlike richness of the dung of the horse and of the cow. The latter animal, when full grown and not in milk, voids nearly 13 times as much urine as the former (Part III., p. 244), and though an equal bulk of this urine is poorer in solid matter, yet the whole quantity contains several times as much as is present in that of the horse. But if the cow discharges more in its urine it must void less in its solid excretions. Hence, supposing the food of a full grown horse and of a cow to be very nearly the same, the dung of the former—the less-urine-giving animal—must be the richer, the warmer, and the more valuable—as it is really known to be.

3°. *By the amount of exercise or labour to which the animal is subjected.*—The greater the fatigue to which an animal is subjected, the richer the urine is found to be in those compounds (urea chiefly) which yield ammonia by their decomposition (Prout). The food of two animals, therefore, being the same—other things also being equal—the solid excretions will be richer and more fertilizing in that which is kept in the stall or fold-yard, the urine in that which is worked in the open air or pastured in the field.

4°. *By the state of growth to which the animal has arrived.*—A full grown animal has only to *keep up* its weight and condition by the food it eats. Every thing which is not necessary for this purpose, therefore, it rejects either in its solid or in its liquid excretions. A young animal, on the other hand, *adds to and increases* its bone and muscle at the expense of its food. It rejects, therefore, a smaller proportion of what it eats. Hence the manure in fold-yards, where young cattle are kept, is always less rich than where full grown animals are fed.

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* *Lehre vom Dünger*, p. 142.

† 12 loads of the dung of animals fed (while fattening) chiefly upon oil-cake was found to give a greater produce than 24 loads from *store* stock fed in the straw-yard.—*Complete Grazier*, sixth edition, p. 103.

5°. *By the purpose for which the animal is fed.*—Is it to be improved in condition? Then the food must supply it with the materials for increasing the size and strength of its muscles—with albumen, or fibrin, or other substances containing nitrogen. In such substances, therefore, or in nitrogen derived from them, the droppings must be poorer, and as a manure, less valuable.

Is the animal to be fattened? Then its food must supply fatty matters, or their elements, of which nitrogen forms no part. All the nitrogen of the food, therefore, will pass off in the excretions, and hence the richest manure yielded at any time by the same species of animal is that which is obtained when it is full grown, and being largely fed, is rapidly fattening.

Is the cow kept for its milk? Then the milk it yields is a daily drain upon the food it eats. Whatever passes into the udder is lost to the dung, and hence, *other things being equal*, the dung of a milk cow will be less valuable to the farmer than that of a full-grown animal from which no milk is expected, or than that of the same animal when it is only laying on fat.

6°. *By the length of time during which the manure has been kept.*—In 24 hours, as we have seen, the dung of the horse begins to ferment and to lessen in weight. All rich manures, in like manner—the dung of all animals especially—decompose more or less rapidly and part with their volatile constituents. The value we assign to them to-day, therefore, will not apply to them to-morrow, and hence the droppings of the same animal at the same age, and fed in the same way, will be more or less valuable to the farmer according to the length of time during which they have been permitted to ferment.

7°. *Lastly. By the way in which the manure has been preserved.*—The mixed dung of the farm-yard must necessarily be less valuable where the liquid manure is allowed to run off, or where it is permitted to stand in pools and ferment. Twenty cart-loads of such dung may hasten the growth of the turnip crop in a less degree than half the weight will do where the liquid manure has been carefully collected and returned upon the heaps—to hasten and complete their fermentation, and to saturate them with enriching matter.

Since, then, the quality or richness of the dung of the same animal is liable to be affected by so many circumstances, it is obvious that no accurate general conclusions can be drawn in regard to its precise fertilizing virtue when applied to this or to that crop, or to its relative fertilizing value when compared with equal weights of the dung of other animals. The results obtained in one set of analyses, as in that of Boussingault, or in one series of practical experiments, as in that of Hermbstädt (Part III., p. 258), will not agree with those obtained in any other; because the substances themselves with which our different experiments are made, though called by the same name, are yet very unlike in their chemical properties and composition.

§ 16. *Of the changes which the food undergoes in passing through the bodies of animals.*

It is the result of long experience that vegetable matter is more sensibly active as a manure, after it has passed through the body of an animal, than if applied to the land in its unmasticated and undigested state. In becoming *animalized*, therefore—as it has been called—vegetable substances have been supposed to undergo some mysterious, because not very obvious or intelligible, internal change, by which this new virtue is imparted to them. Yet the change is very simple, and when explained is not more satisfactory than it is beautiful.

You will recollect, as I have already stated to you (Part III., p. 257) that *the weight of dry manure voided by an animal is always considerably less than that of the dry food eaten by it.* Upon the nature and amount of this loss which the food undergoes depends the quality of the manure obtained.

This you will readily comprehend from the following statement.

1°. Every thing which enters into the body in the form of food must escape from the body in one or other of three different forms. It must be breathed out from the lungs, perspired by the skin, or rejected in the solid or liquid excretions. We have already seen (Part I., p. 223) that the function of the lungs is to give off carbon in the form of carbonic acid, while they drink in oxygen from the air —and that the quantity of carbon thus given off by a healthy man varies from 5 to 13 or more ounces in the 24 hours. From the skin also carbon escapes, along with a small and variable proportion of saline matter. The weight of carbon given off by the skin has not been accurately ascertained. Let us leave it out of view for a moment, and consider solely the effect of respiration upon the nature of the solid and liquid excretions.

Suppose a healthy man, taking a moderate degree of exercise, to give off from his lungs 6 ounces of carbon in 24 hours, and to eat during the same time 2 lbs. of potatoes, half a pound of beef, and half a pound of bread. Then he has

Taken in his food	Carbon.	Nitrogen.	Saline matter.
In the potatoes -	1716 grs.	47 grs.	196 grs.
In the bread -	1004 ..	34 ..	22 ..
In the beef -	790 ..	120 ..	35 ..
	3510 grs.	201 grs.	253 grs.
And he has given off in respiration	2625 grs.		
Leaving to be rejected sooner or later in the excretions	885 grs.	201 grs.	253 grs.

In this supposed case, therefore, the carbon, nitrogen, and saline matter were to each other nearly as the numbers

	Carbon.		Nitrogen.		Saline matter.	
	35	-	2	-	2½	in the food,
and as	9	-	2	-	2½	in the excretions ;

or, in other words, the carbon being in great part sifted out of the food by the lungs, the excretions are necessarily much richer in nitrogen and in saline matter, *weight for weight*, than the mixed vegetable and animal matters on which the man has lived.

But the immediate and most sensible action of animal and vegetable substances, as manures, depends upon the proportion of nitrogen and saline matters they contain. This proportion, then, being greater in the excretions than in the crude vegetables, the cause of the higher estimation in which the former are held by the practical farmer is sufficiently clear.

2°. In the above case I have supposed the allowance of food to be such only as a person of sedentary habits would consume, and the quantity of carbon given off from the lungs to be such as his habits would occasion. But if the weight of carbon given off from the lungs and skin together amount, as it often does, to 15 ounces,* the quantity of food must be greatly increased beyond the quantity I have stated, if the health and strength are to be sustained. By such an increase of food—the carbon being removed by respiration—the proportion of nitrogen and of saline matters in the excretions may be still further increased, or as manures they may become still richer and more *immediately* fertilizing.

3°. Let me present to you the results of an actual experiment made by Boussingault upon a horse fed with hay and oats, and of which both the food and the excretions were carefully analyzed.

In 24 hours the horse consumed—

	Carbon. grs.	Nitrogen. grs.	Saline matter. grs.
Hay 16½ lbs.,† containing -	45,500	1,500	8,960
Oats, 5 lbs. - - -	15,000	650	1,180
Total in the food - -	60,500	2,150	10,140
And gave off from the lungs and skin - - -	37,960		
Leaving to be rejected in the excretions - -	22,540	2,150	10,140
Where there was actually found in the mixed dung	22,540	1,770	10,540

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* Liebig estimates the quantity of carbon which escapes from the lungs and skin of a healthy man, taking moderate exercise, at 13·93 ounces (Hessian), or 15¼ ounces avoirdupois, in 24 hours.

† Each containing about 14 per cent. of water.—*Annales de Chim. et de Phys.*, lxxi., p. 136.

In this case, then, the carbon, nitrogen, and saline matter were contained in the proportions of—

	Carbon.		Nitrogen.		Saline matter.	
	28	-	1	-	5	in the food,
and of	10½	-	1	-	5	in the dung;

the analysis of the dung itself proving that in passing through the body of an animal, the food—

a diminishes very considerably in weight;

b losing a large but variable proportion of its carbon,

c but parting with scarcely any of its nitrogen and saline matter—and therefore

d that the fertilizing virtues of the dung above that of the food of animals—*weight for weight*—depends mainly upon the larger proportion of these two constituents (the nitrogen and the saline matter) which the dung contains.

I have only further to remind you upon this subject, that the state of combination also in which the nitrogen exists in the excretions has a material influence in rendering their action more immediate and sensible than that of unchanged vegetable matter. It passes off for the most part in the form of urea, which is resolved into ammonia and its compounds more rapidly than the albumen of the dried or even of the recent plant, and is thus enabled sooner to exert an appreciable influence upon the growing crop.

§ 17. *Of farm-yard manure, and of the state in which it ought to be applied to the land.*

The manure of the farm-yard consists, for the most part, of cow-dung and straw mixed and trodden together, in order that the latter may be brought into a state of decomposition. In the improved husbandry, where green crops are extensively grown and many cattle are kept, the horse dung forms only a small proportion of the whole manure of the farm-yard.

On an average, the quantity of recent manure obtained in the farm-yard amounts to a little more than twice the weight of the dry food of the cattle and of the straw spread in the farm-yard or in the stables (Part III., 257.) That is to say, for every 10 cwt. of dry fodder and bedding, 20 to 23 cwt. of fresh dung may be calculated upon. But if green clover or turnips (every 100 lbs. of which contain from 70 to 90 lbs. of water) be given to the cattle, an allowance must be made for the water they contain—the quantity of mixed manure to be expected being from 2 to 2½ times the weight of the *dry* food and fodder only.

But the recent manure loses weight by lying in the farm-yard. The moisture evaporates and volatile matters escape by fermentation. By the time that the straw is half-rotten this loss amounts to *one-fourth* of the whole weight, while the bulk is diminished one-half. If allowed to lie still longer the loss increases, till at length it may approach to one-half of the whole, leaving a weight of dung little greater than that of the food and straw which have been consumed. The weight of common mixed farm-yard dung therefore obtained from 10 cwt. of dry food and straw, at different periods, may be thus stated *approximately*—

10 cwt. of dry food and straw yield of recent dung	23 to 25 cwt.
At the end of six weeks	21 cwt.
After eight weeks	20 cwt.
When half-rotten	15 to 17 cwt.
When fully rotten	10 to 13 ...[*]

These quantities, you will observe, are supposed to be obtained in the common open farm-yards, with the ordinary slow process of fermentation. An improved, quicker, or more economical mode of fermenting the mixed dung and straw may be attended with less loss, and may give a larger return of rich and fully-rotten dung.

A knowledge of these facts shows clearly what is the most economical form in which farm-yard manure can be applied to the land.

1°. The more recent the manure from a given quantity of food and straw is ploughed in, the greater the quantity of organic matter we add to the land. When the *only* object to be regarded, therefore, is the general enriching of the soil, this is the most economical and the most expedient form of employing farm-yard manure.

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[*] In an excellent little practical work printed for private circulation, under the title of "*Notes on the Culture and Cropping of Arable Land*," by the late Dr. Coventry, of Edinburgh, the reader will find a valuable section upon manures. The most complete work now in existence upon the general subject of agricultural statics, is that of Hlubek, *Die Ernährung der Pflanzen und die Statik des Landbaues*.

2°. But where the soil is already very light and open, the ploughing in of recent manure may make it still more so, and may thus materially injure its mechanical condition. In such a case the least of two evils must be chosen. It may be better husbandry—that is, more economical—to allow the manure to ferment and consolidate in the farm-yard with the certainty of a considerable loss, than to diminish the solidity of the land by ploughing it in in a recent state.

3°. Again—in the soil, a fermentation and decay similar to that which takes place in the farm-yard, will slowly ensue. The benefit which generally follows from causing this fermentation to take place in the field rather than in the open yard is, that the products of the decomposition are taken up by the soil, and thus waste is in a great measure prevented. But in very light and open soils, this absorption of the products of decay does not take place so completely. The rains wash out some portions, while others escape into the air, and thus by burying the recent manure in such soils, less of that waste is prevented which when left in the open air it is sure to undergo. It may even happen, in some cases, that the waste in such a soil will not be greatly inferior to that which necessarily takes place in the farm-yard. The practical man, therefore, may question whether, as a general rule, it would not be safer in farming very light arable lands, to keep his manure in heaps till it is well fermented, and to adopt those means for preventing waste in the heaps themselves which science and practical skill point out to him.

It may be regarded indeed as a prudent general opinion to hold—one, however, which must not be maintained in regard to any particular tract of land in opposition to the results of enlightened experience—that recent farm-yard manure (*long dung*) is not suited to very light soils, because it will render them still lighter, and because in them the manure may suffer almost as much waste as in the farm-yard; and, therefore, that into such soils it should be ploughed in the compact state (*short dung*), and as short a time as possible before the sowing of the crop which it is intended to benefit.

4°. But upon loamy and clay soils the contrary practice is recommended. Such soils will not be injured, they may even be benefitted by the opening tendency of the unfermented straw, while at the same time the products of its decomposition will be more completely retained—the land consequently more enriched, and the future crops more improved by it. On such soils, the recent dung ploughed in, in the autumn, has been found greatly more influential upon the crops of corn which followed it, either in winter or in spring, than a *proportional* quantity of well fermented manure. By such treatment, indeed, the whole surface-soil is converted into a layer of compost, in which a slow fermentation proceeds, and which reaches its most fertilizing condition when the early spring causes the young corn to seek for larger supplies of food.

5°. But the nature of the crop he is about to raise will also influence the skilful farmer in his application of long or short dung to his land. If the crop is one which quickly springs up, runs through a short life, and attains an early maturity, he will apply his manure in such an advanced state of fermentation as may enable it *immediately* to benefit the rapidly growing plant. In this case also, it may be better to lose a portion by fermenting it in the farm-yard, than, by applying his manure fresh, to allow his crop to reach nearly to maturity before any benefit begins to be derived from it.

6. So also the *purpose* for which he applies his manure will regulate his procedure. In manuring his turnips the farmer has two distinct objects in view. He wishes, first, to force the young plants forward so rapidly that they may get into the second leaf soon enough to preserve them from the ravages of the fly—and afterwards to furnish them with such supplies of food as shall keep them growing till they have attained the most profitable size. For the former purpose fermented manure appears to be almost indispensable—if that of the farm-yard is employed

at all—for the latter, manure in the act of slow and prolonged decomposition, is the most suitable and expedient.

It is because bone-dust is admirably adapted for both purposes, that it has become so favourite a manure in many districts for the turnip crop. The gelatine of the outer portion of the bones soon heats, ferments, and gives off those substances by which the young plant is benefitted—while the gelatine of the interior of the bone decays, little by little, and during the entire season continues to feed the maturing bulb. Rape-dust, when drilled in, acts in a similar manner, if the soil be sufficiently moist. It may be doubted, however, whether its effects are so permanent as those of bones.

The considerations I have now presented will satisfy you that the disputes which have prevailed in regard to the use of long and short dung have arisen from not keeping sufficiently distinct the two questions—what is *theoretically* the best form in which farm-yard dung can be applied *in general?*—and what is *theoretically* and *practically* the best form in which it can be applied to this or to that *crop*, or for this or that *special object?*

§ 18. *Of top-dressing with fermenting manures.*

If so large a waste occur in the farm-yard where the manure is left long to ferment—can it be good husbandry to spread fermenting manure as a permanent top-dressing over the surface of the fields? This, also, is a question in regard to which different opinions are entertained by practical men.

That a considerable waste must attend this mode of application there can be no doubt. Volatile matters will escape into the air, and saline substances may be washed away by the rains, and yet there are many good practical farmers who consider this mode of applying such manure to be in certain cases as profitable as any that can be adopted. Thus—

1°. It is common in spring to apply such a top-dressing to old pasture or meadow lands, and the increased produce of food in the form of grass or hay is believed to be equal, at least, to what would have been obtained from the same quantity of manure employed in the raising of turnips. Where such is really the case experience decides the question, and pronounces that notwithstanding the loss which must occur, this mode of applying the manure is consistent with good husbandry. But if the quantity or market value of the food raised by a ton of manure applied in this way is not equal to what it would have raised in turnips and corn, then it may as safely be said that the most economical method of employing it has not been adopted.

But theory also throws some interesting light upon this question.

Old grass lands can only be manured by top-dressings. And if they cannot continue, and especially such as are meadowed, to yield an average produce unless there be now and then added to the soil some of those *same* substances which are carried off in the crop, it appears to be almost necessary that farm-yard dung should now and then be applied in some form or other. It is true that hay or straw or *long dung* contains all the elements which the growing grass requires, but if spread on the surface of the field and then allowed to ferment and decay, the loss would probably be still greater than when, for this purpose, it is collected into heaps or strewed in the farm-yard. Thus the usual practice of laying on the manure in a highly-fermented state *may* be the most economical.

2°. Again, where the turnip crop is raised in whole or in part by means of bones only, of rape-dust, or of other artificial manures, as they are called, it is usual to expend a large proportion of the farm-yard dung in top-dressing the succeeding crop of clover. Thus the land obtains two manurings in the course of the four years' rotation—bones or rape-dust with the turnips, and fermented dung with the clover. This second application increases the clover crop in some districts one-fourth and the after crop of wheat or barley very considerably also.*

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* Such is the case upon some of the farms in the Vale of the Thame (Staffordshire), where the turnips are raised with rape-dust, and wheat follows the clover.

Here also it is clear that if manure be necessary to the clover, it can only be applied in the form of a top-dressing. But why is it necessary, as experience says, and why should farm-yard manure, which is known to suffer waste, be applied as a top-dressing rather than rape-dust, which in ordinary seasons is not so likely to suffer loss? I offer you the following explanation :—

If you raise your turnip crop by the aid of bones or rape-dust alone, you add to the soil what, in most cases, may be sufficient to supply nearly all the wants of that crop, but *you do not add all which the succeeding crops of corn and clover require.* Hence, if these crops are to be grown continuously, and for a length of time, some other kind of manure must be added, in which those necessary substances or kinds of food are present which the bones and rape-dust cannot supply. Farm-yard manure contains them all. This is within the reach of every farmer. It is, in fact, his natural resource in every such difficulty. He has tried it upon his clover crop in the circumstances we are considering, and has necessarily found it to answer.

Thus to explain the results at which he has arrived in this special case, chemical theory only refers the practical man to the general principle upon which all scientific manuring depends—that *he must add to the soil sufficient supplies of every thing he carries off in his crops*—and, therefore, that without some such dressing as he actually applies to his clover crop, he could not long continue to grow good crops of any kind upon his land, if he raise his turnips with bones or rape-dust only.

It might, I think, be worthy of trial, whether the use of the fermented dung for the turnips, and of the rape-dust for top-dressing the after crops, would not, in the entire rotation, yield a larger and more remunerating return.

§ 19. *Of eating off with sheep.*

The practical advantages derived from eating off turnips and clover crops with sheep are mainly of two kinds. Light lands are trodden down and solidified, and they are at the same time equably and more or less richly manured. With this latter effect, that of manuring, some interesting practical facts and theoretical considerations are connected. Thus—

1°. In the preceding lecture (Part III., p. 180) I mentioned to you that in some parts of Germany, spurry, among other plants, is extensively grown, and with much profit, for ploughing in as a green manure. Now it is mentioned that the crops of rye which follow a crop of spurry are sometimes quite as great when it has been eaten off with sheep or cattle as when it has been ploughed in.*

2°. In accordance with this statement is the opinion of many skilful practical men among ourselves that a crop of clover or of tares will cause a larger after growth of corn, if it be eaten off with sheep, than if it be ploughed in in the green state.

The correctness of these practical observations appears from a brief consideration of one of those interesting theoretical questions we have recently been discussing.

When a crop is eaten off by full-grown animals, it returns again to the soil, deprived of [illegible] portion of its carbon only (Part III., p. 264). The manure contains all the nitrogen and saline matter of the green vegetables, and in a state in which they are more immediately available to the uses of the young plant. Thus far, then, we can understand that in certain cases a crop may appear to fertilize the land more after it has been eaten and digested, than if it had been ploughed in green, and we can recognize the correctness of the opinion at which practical men have arrived.

But theory does not forsake us here. As in all other cases in which it furnishes a true explanation of known facts, it points to new facts also, which more or less modify our received opinions, and define the limits within which their truth can be rigorously maintained. Thus—

1°. Theory says that if the animals fed upon the green crop be in a growing state—if they be increasing in muscle or in bone—they will not only dissipate through their lungs and skin a portion of its carbon, but will retain also a part of its nitrogen and saline matter, and will thus return to the soil, in their excretions, a smaller quantity of these substances than the crop would have given to it if ploughed in green. If, therefore, a maximum fertilizing effect is to be produced upon a field by eating off a green crop, it is not altogether a matter of indifference what kind of animals we employ as digesters.

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* Von Voght, *Über Manche Vortheile der grüner dungung.*

2°. Again, the practice of green manuring is resorted to chiefly upon soils which are poor in organic matter—to which the *carbon* of the green crop is of consequence, as well as the nitrogen and saline matter it contains. But when eaten off, much carbon is lost to the soil, and thus the supply of organic matter which it ultimately gets is considerably less than if the crop it bore had been ploughed in in the green state. Such soils, then, cannot be equally enriched by the former as by the latter method.

This case presents a very interesting illustration, and one which you can readily appreciate, of the kind of useful information which theoretical chemistry is capable of imparting upon almost every branch of practical agriculture. It says to the farmer—yes, you may in some cases, certainly, eat off the crop with advantage; but if you wish to do most good to your land you must eat it off with fattening not with growing sheep, and you must do so upon soils which are not very poor in vegetable matter. And that explains to me also, says the practical man, in reply, why I have always found sheep-folding to be most beneficial on soils which are rich in vegetable matter.* (Part III., p. 257).

§ 20. *Of the improvement of the soil by irrigation.*

Irrigation, as it is practised in our climate, is only a more refined method of manuring the soil. In warm climates, where the parched plant would wither and die unless a constant supply of water were artificially afforded to it, irrigation may act beneficially by merely yielding this supply to the growing crops; but in our latitudes only a small part of its beneficial effects can be ascribed to this cause. It is to pasture and meadow lands almost solely that irrigation is applied by British farmers, and the good effect it produces is to be explained by a reference to various natural causes.

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* Sprengel explains this fact by alleging that the humic acid of the vegetable matter retains more effectually the ammonia of the decomposing dung. There may be something in this, but more in most cases, I think, in the fact that digestion separates much of the carbon in which the soils abound but returns the nitrogen and saline matter almost entirely and in a more active state.

1°. If the water be more or less muddy, bearing with it solid matter which deposits itself in still places, the good effects which follow its diffusion over the soil may be ascribed to the layer of visible manure which it leaves every where behind it. Thus the Nile and the Ganges fertilize the lands over which their annual floods extend, and partly in this way do some of our smaller streams improve the fields over which they either naturally flow or are artificially led.

2°. Or if the water hold in solution, as the liquid manures of the farm-yard do, substances on which plants are known to feed, then to diffuse them over the surface is a simple act of liquid manuring, from which the usual benefits follow. Such is the irrigation which is practised in the neighbourhood of our large towns, where the contents of the common sewers are discharged into the waters which subsequently spread themselves over the fields.* In so far also as any streams can be supposed to hold in solution the washings of towns or of higher lands—and there are few which are not more or less impregnated in this manner—so far may their beneficial action, when employed for purposes of irrigation, be ascribed to the same cause.

3°. But spring waters which have run only a short way from their source are occasionally found to be valuable irrigators. In such cases also, the good effect may be due in whole or in part to substances held in solution by the water. Thus, in lime-stone districts, and especially those of the mountain lime-stone formation (Part II., p. 366)—in which copious springs are not unfrequently met with—the water is generally impregnated with much carbonate of lime, which it slowly deposits as it flows away from its source. To irrigate with such water is, in a refined sense, to lime the land, and at the same time to place within the reach of the growing plants an abundant supply of this substance in a form in which it can readily enter into their roots.*

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* For an interesting account of the effects of such irrigation in the neighbourhood of Edinburgh, see Stephens *on Irrigation and Draining*, p. 75.

In other districts, again, the springs contain gypsum and common salt, and sulphate of soda and sulphate of magnesia, and thus are capable of imparting to plants many of those inorganic forms of matter, without which, as we have seen, they cannot exhibit a healthy growth.

4°. Again, it is observed that the good effects of irrigation are produced only by *running water*—coarse grasses and marsh plants springing up when the water is allowed to stagnate.† This is explained in part by the fact that a given quantity of water will soon be deprived of that portion of matter held in solution, of which the plants can readily avail themselves, and that when this is the case it can no longer contribute to their growth in an equal degree.

But there is another virtue in running water, which makes it more wholesome to the living plant. It comes upon the field charged with gaseous matter, with oxygen and nitrogen and carbonic acid, in proportions very different from those in which these gases are mixed together in the air (Part I., p. 49). To the root, and to the leaf also, it carries these gaseous substances. The oxygen is worked up in aiding the decomposition of decaying vegetable matter. The carbonic acid is absorbed by and feeds the plant. Let the same water remain on the same spot, and its supply of these gaseous substances is soon exhausted. In its state of rest it re-absorbs new portions from the air with comparative slowness. But let it flow along the surface of the field, exposing every moment new particles to the moving air, and it takes in the carbonic acid especially with much rapidity, and as it takes it from the air, almost as readily again gives it up to the leaf or root with which it first comes into contact. This is no doubt one of the more important of the several purposes which we can understand running water to serve when used for irrigation.

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* Some of the water used in the well-known scientific irrigations at Closeburn Hall, in Dumfries-shire, appears to have been impregnated with lime. See Stephens, p. 43.

† Low's *Elements of Agriculture*, 3d edition, p. 472.

But further, if water be allowed to stagnate over the finer grasses, they soon find themselves in circumstances in which it is not consistent with their nature to exhibit a healthy growth. They droop, therefore, and die, and are succeeded by new races, to which the wet land is more congenial.

5°. It is known also that even running water, if kept flowing without intermission for too long a period, will injure the pasture. This is because a long immersion in water induces a decay of vegetable matter in the soil which is unfavourable to the growth of the grasses—producing chemical compounds which are not naturally formed in those situations in which the grasses delight to grow, and which are unwholesome to them. Although, therefore, the water continues to supply those various kinds of food by which the grasses are benefitted, yet it becomes necessary to withdraw it for a time in order that other injurious consequences may be avoided.

6°. *Lastly.*—Irrigation is most beneficial where the land is well drained beneath—where the water, after the irrigation is stopped, can sink and find a ready outlet. The same benefits indeed flow from the draining of irrigated as from that of arable lands. The soil and subsoil are at once washed free of any noxious substances they may naturally contain, or may have derived from the crops they have grown, and are manured and opened up by the water which passes through them. As the water descends also, the air follows it, to change and mellow the under-soil itself.

Such are the main principles upon which the beneficial action of irrigation depends, and they appear to me satisfactorily to account for all the facts upon the subject with which I am acquainted. I pass over the alleged beneficial action of water in keeping the temperature of irrigated fields from sinking too low. As irrigation is practised in our islands, little of the good done to watered meadows can be properly attributed to this cause.

I have now drawn your attention to the most important and readily available means, mechanical and chemical, for improving the soil. Let us next study the products of the soil—their composition, their differences, and the purposes they are intended to serve in the feeding and nourishment of animals.

APPENDIX.

No. I.

SUGGESTIONS FOR EXPERIMENTS IN PRACTICAL AGRICULTURE DURING THE ENSUING SPRING AND SUMMER.

One of the most important objects which chemistry is at present desirous of attaining for the improvement of practical agriculture, is the discovery and application of specific or *special* manures.

We know that certain substances, such as fold-yard manure, are capable of fertilizing to a considerable extent almost any land, and of causing it to yield a better return of almost any crop. But we know also that manures or fertilizers of nearly every kind are more efficacious on one soil than on another, and that some answer better also for one species of crop than for another. The case of gypsum will serve to illustrate both these positions.

The effects of gypsum in the United States, in Prussia, and other parts of Germany, and in some districts of England, are said to be absolutely astonishing; while in many other parts of our Island, of Germany, and even of the United States, the benefit derived from it has not repaid the trouble and expense incurred in applying it. Gypsum, therefore, is *specially adapted* for use in certain soils only.

Again, the remarkable effects of gypsum have been observed most distinctly on clover* and certain kinds of grass. The same benefits have not followed, to any thing like an equal extent, from its use on barley, oats, wheat, or other kind of grain. Therefore, while specially adapted to certain soils, it is also specially adapted to certain crops. It is a kind of specific manure for clover and some of the grasses.

Now, neither of these subjects which it is so important to investigate,—neither that of the manures which are especially fitted for each soil, nor of those which are especially fitted for each crop, —can be determined either from theory or from experiments devised and executed in the laboratory of a chemist. The aid of the practical farmer, of many practical farmers, must be called in. Numerous experiments, or trials, must be made in various localities, and by different individuals,—all, however, according to the same rigorous and accurate method,—in order that, from the comparison of many results, something like a general principle may be deduced.

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* In regard to its use in Germany, Lampadius says,—"It may, with certainty, be stated, that by the use of gypsum the produce of clover and the consequent amount of live stock have been increased *at least one-third*."—DIE LEHRE VON DEN MINERALISCHEN DUNGMITTELN, p. 34.

It is partly with a view to determine the mode of action of certain fertilizers, and partly in the hope of obtaining some additional light on the subject of manures *specifically adapted to particular crops*, that I venture to suggest to you the propriety of making one or more of the following sets of experiments, during the spring and summer of the present year. I could have much enlarged the list of suggestions, but I neither wish to fatigue your attention, nor to place before you more work of the kind than can be readily accomplished, *with little expense* of time, labour, or money. Another season will, I hope, afford us an opportunity of interrogating nature by further, and perhaps more refined, modes of experimenting.

I. *Of Grass and Clover.*

1°. It is beyond dispute, that on certain soils, gypsum causes a largely increased growth of grass and clover, but experiment alone appears capable of determining on *what* soils it is likely to be thus beneficial. Such experiments, therefore, ought to be made on every farm, on a small scale at first, and at little cost,[*] but made with care and accuracy, and with a minute attention to weights and measures.

2°. The action of gypsum appears to be entirely chemical, but the only explanation of this action yet attempted is far from being satisfactory. It is desirable, therefore, that experiments with other substances should be made, which are likely to throw light on the theory. Important practical results may at the same time be obtained—they are sure, indeed, to follow from a right understanding of the theory.

In the neighbourhood of Lyons, it has been found that very dilute sulphuric acid[†] (oil of vitriol) exhibits the same beneficial effect upon clover, that has elsewhere attended the use of gypsum.

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[*] The price of gypsum in London is about 2s. 6d. per cwt.; in Newcastle, 3s.

[†] Gypsum consists of *sulphuric acid* and *lime*.

It is desirable, therefore, that a comparative experiment should be made with this acid on a portion of the same field to which the gypsum is applied. Where the one fails the other may act.

3°. It was observed by Dr. Home, of Edinburgh, so early as the year 1756, that sulphate of soda* had a remarkable effect in promoting the growth of plants—its action being nearly equal to that of saltpetre or nitrate of soda. This fact, though mentioned by Lord Dundonald, has been lost sight of by practical men, the sulphate of soda being generally represented as too high in price to be available as a fertilizer.† The use of saltpetre, however, and of nitrate of soda, both of which are more than double the price of sulphate of soda, show that the cost of this latter article ought not to stand in the way of an accurate trial of its value as a fertilizer on various crops. Dry sulphate of soda can be readily obtained from any of the alkali works on the Tyne,‡ and being an article of domestic manufacture, it is proper that its merits should be ascertained, and, if it can be made available, that its use should be encouraged.

From the circumstance of its containing sulphuric acid, therefore, I would recommend that it should be tried on clover and grass, in comparison with gypsum and sulphuric acid, and on a portion of the same field. It may succeed where the others fail.

4°. Nitrate of soda also, as a top-dressing on grass land, has been often used with great benefit. I have seen grass land in Dumfriesshire, which, after being long let for pasture at 30s. an acre, had been sprinkled with an annual top-dressing of nitrate of soda at the rate of 20s. an acre, and had since readily let at £4 an acre, yielding thus an annual profit of 30s. an acre to the landlord.

In other districts, again, it has been found to answer better for corn. Thus, after a discussion on this subject in the Gloucester Farmers' Club, it was agreed, that nitrate of soda "was a very valuable manure for white straw crops, but when applied to green crops the benefit was not sufficiently great to counter-balance the expense." In Northumberland, where it has been tried in a skilful manner by Mr. Gray, of Dilston, it was found to yield a most profitable return on both hay and barley.

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* *Glauber salts*—consisting of sulphuric acid and soda.

† Lord Dundonald says—"From experiments it has been proved to promote vegetation in a very high degree. The high price at present of this article precludes the use of it, but could it be made and sold at a cheap rate, it would prove a most valuable acquisition to agriculture." Since the time of Lord Dundonald some trials made in Germany have shown it to have a beneficial action on rye, potatoes, and fruit trees.

‡ Messrs. Allan & Co., of the Heworth Alkali Works, deliver it in Newcastle and the neighbouring towns, at 9s. or 10s. per cwt.

These results show the necessity of further trials, not only for the purpose of illustrating the cause of the beneficial action of this saline substance, but also with the view of arriving at some general rule by which the practical man may be guided in determining on *what fields* and for *what crops on those fields*, the nitrate of soda may be beneficially applied.

This experiment, like the others above-mentioned, will be much more valuable, if made in such a way that the result can be compared with that obtained by the use of other chemical agents. I would, therefore, propose that in the same field of grass or clover, a portion should be measured off, to be top-dressed with nitrate of soda, that thus not only the *absolute*, but also the *comparative*, weight of the produce may at the same time be ascertained.

5°. There are other trials also, from which this general subject is capable of receiving illustration. The fertilizing power of gypsum has been explained by its supposed action on the ammonia which is presumed to exist in the atmosphere. If this be the true explanation, a substance containing ammonia should act *at least* as energetically. At all events, the action of fold-yard manure and of putrid urine is supposed to depend chiefly on the ammonia they contain or give off. Now, among the substances containing ammonia in large quantity, which in most towns are allowed to run to waste, the ammoniacal liquor of the gas works is one which can easily be obtained, and can be applied in a liquid state at very little cost. It must be previously diluted with water till its taste and smell become scarcely perceptible.

I would propose, therefore, as a further experiment, that along with one or more of the substances above-mentioned, the ammoniacal liquor of the gas works should be also tried, on a measured portion of ground, and, if possible, in the same field.

6°. Soot, as a manure, is supposed to act partly, if not chiefly, in consequence of the ammonia it contains. In Gloucestershire it is applied to potatoes and to wheat, chiefly to the latter, and with great success. In the Wolds of Yorkshire it is also applied largely to the wheat crop, at the rate of about 24 bushels to the acre.* In this county it is frequently used on grass land, to the amount of 20 bushels an acre, and though I am not aware that it is extensively employed upon clover, I am inclined to anticipate that the sulphur it contains,† in addition to the ammonia, would render it useful to this plant. At all events, comparative experiments in the same field with the gypsum and the ammoniacal liquor, are likely to lead to interesting results.

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* The price is from 6*d.* to 1*s.* a bushel. In this county the soot *is said* to be often of an inferior quality, and brings therefore a less price.

† The *gypsum*, I might also say, for much of our soot contains gypsum, the lime being derived chiefly from the sides of the flue.

7°. Common salt, highly recommended as a manure by some, has been as much depreciated by others, and hence, when directly applied, is considered as a doubtful fertilizer by almost all. The obscurity in regard to its use, however, rests chiefly on the quantity which ought to be employed. The result of comparative experiments made in Germany, showed that a very few pounds per acre were sufficient to produce a largely increased return of grass—while in England it has been beneficially applied within the wide limits of from five to twenty bushels per acre, and, when used for cleaning the land in autumn, of thirty bushels an acre.

Among the comparative experiments upon grass and clover here suggested, the effect of salt might also be tried with the prospect of practical benefit. It would give an additional interest to the experiments and supply an additional term of comparison.

The entire series of experiments, therefore, which I would recommend, would occupy eight patches on a clover or grass field, one of which would be left *undressed* for the purpose of comparison. Thus, each plot being *half an acre:*

Gypsum.	Sulphate of Soda.	Ammoniacal Liquor.	
Sulphuric Acid.	Nitrate of Soda.	Common Salt.	Soot.

The ammoniacal liquor and the soot are placed as far as possible from the gypsum and sulphuric acid, that they may not interfere with each other's action. In a large field they might be placed still farther apart, and other trials might be made in one or two of the vacant spaces.

The appearance of each patch should be entered, *with the date*, in an experiment book, at weekly intervals, and the final produce both of hay and of aftermath carefully noted, both as to *weight* and *quality*.

Nor will the experiment be completed when the crop for the year is gathered in; but, where it is possible, two further points should be ascertained,—

1°. The relative feeding or nourishing properties of the produce. To those who rear and fatten cattle, this is a matter of great importance, and it is one which they could easily determine, at least very approximately.

2°. What has been the permanent effect of the several substances on the soil, as indicated by the comparative quantity and quality of the crop obtained from each half acre, on the *succeeding* or during the *two following* years. The result of these further observations may materially modify the conclusion we should draw from the comparative weight and quality of the produce of the first year.

I shall only observe, in conclusion, on this head, that the result of a simultaneous trial of all these substances in the same field would not only throw much light on the specific action of each on the grass or clover in general, but would be of permanent utility to that farm or locality in which the experiments were made. It would indicate the kind of fertilizer which was best adapted to the farm or neighborhood in the existing condition of its general culture. It would form a local record, useful not only to the tenant who made the experiment (if well made) and by whom the farm at the time was tenanted, but more useful by far, and more permanently so, to the owner of the land whose interest in it is supposed to be not only greater, but much more lasting.

In regard to the *quantities* of the several substances above-mentioned, which are to be applied to each acre, they may probably be varied according to circumstances, but the following may be recommended in the comparative experiments:

1°. Gypsum 2 to 3 cwt. per acre.

2°. Sulphate of Soda 1 cwt. per acre.

3°. Nitrate of Soda 1 cwt. per acre.

4°. Soot 20 bushels per acre—this in different districts may be varied according to the known quality of the soot.

5°. Of Sulphuric Acid from 30 to 40 lbs. per acre, applied at three or four several intervals—and diluted with at least 200 times its weight of water. Or so much water may be added as to make it perfectly tasteless, or so weak as not sensibly to injure the texture of a plant left in it during the previous night.*

6°. Of Ammoniacal Liquor 100 to 200 gallons per acre, according to its strength, for this is constantly varying. It must also be diluted with so large a quantity of water as will render it perfectly tasteless, and is likely to prove most beneficial if laid on at several successive periods.

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* The quantity above-mentioned amounts to about two gallons of the acid of the shops, and it should be diluted with three or four hundred gallons of water.

7°. Of common salt it will be safer to apply not more than four to six bushels an acre ; though, where time and circumstances permit, comparative trials might also be made on the efficacy of salt when applied in different proportions, to the *same* land on which the other experiments are made.

As to the *time* when these several dressings ought to be applied, some variation may be made according to the state of the young crop. They need not, in general, be used before the 10th of April, and they should rarely be later than the middle of May.

It will be desirable that in the detail of every set of experiments, the kind and quality of the soil (and subsoil) should be stated—with its drainage and exposure—and the kind of grass or clover which had been sown upon it.

II. *Of Wheat, Barley, and Oats.*

It is known that saltpetre and nitrate of soda produce highly beneficial effects on all these varieties of grain. There remains much to be done, however, before the principle of their operation, or the circumstances on which their most useful application depends, can be clearly understood. Their relative effects on the same kind of grain must be made the subject of more frequent, more precise, and more carefully conducted experiments—and these effects must be compared with those of other fertilizing substances, in order that we may arrive ultimately at some comparative estimate of the practical value of each, in increasing the growth and produce of those crops which are the staples of animal food.

A.—*Of Wheat.*

It is confidently stated by some, as a *general* rule, that saltpetre is more advantageous than nitrate of soda, when applied to wheat. On the other hand, it is beyond question that the application of nitrate of soda to wheat has been found productive of remarkable benefit.

Is saltpetre *specially* adapted for wheat of *all varieties*, on *all soils*, and *under every variety of management*, and is nitrate of soda, in like manner, specially fitted for barley and oats ?

These are questions to which the experiments hitherto made do not enable us to give a reply. New data must be obtained before we can have the means of reasoning usefully in regard to any of them. I would propose, therefore,—

1°. That where two varieties of wheat are sown on the same field, or on different fields of precisely the same kind of land and in the same condition, that two half acres of each variety should be measured off, and that one half acre of each should be dressed with saltpetre, and the other with nitrate of soda, at the rate of 1 cwt. per acre. If three varieties could be so treated, the experiment would be the more valuable.

It would thus be determined how far the effect of each of these nitrates was dependant upon the *variety* of wheat sown—and what was the relative action of each nitrate upon any of the varieties.

2°. That when the same varieties of wheat are sown upon two or more different soils—in different parts of a farm—that one portion of the wheat on every different soil should be dressed with nitrate of soda, and another with nitrate of potash (saltpetre). By this experiment, it would be shown how far the effect of these substances is dependant on the nature of the soil, and how far the action of the one, compared with that of the other, is modified by diversity of soil.

In these different experiments, the management is presumed to be the same. If the experiments be repeated by several persons in different parts of the country, the effects of difference of management will, in a great measure, be shown in the diversity of the results.

3°. With the view of ascertaining the comparative effect of the sulphate of soda on this crop, I would suggest that in each case above specified, an equal area should be set aside to be dressed with this salt, in the proportion of 1 cwt. per acre.

Of each variety of wheat, therefore, and on each variety of soil, four patches of equal area, say half an acre, should be measured off—one of which should be undressed for the purpose of comparison: thus—

Nitrate of Soda.	Saltpetre.
	Sulphate of Soda.

As before, the nature of the soil and the kind of grain must be recorded—the appearance of each patch noted week by week—with the time of ripening and reaping—and the respective qualities and weights of the grain and straw collected from each half acre.

The quantity of gluten contained in the wheat should also be determined, or a sample of the flour transmitted for the purpose to the writer of these suggestions, accompanied by a detail of the experiments they are intended to illustrate.

B.—*Of Barley and Oats.*

To barley and oats the above remarks all apply, with this difference, that to those crops saltpetre is said to be less beneficial than the nitrate of soda. In connection with these crops, however, I would make the following additional observation.

According to any theory of the action of the nitrates of potash and soda which readily presents itself, their effect on any crop which they are equally capable of benefiting ought to be nearly equal, weight for weight. The nitrate of soda ought to have a decidedly more powerful action, were it not that the state of moisture in which it is generally sold, increases its weight so much as in a great measure to deprive it, in equal weights, of this superiority.

But while 1 cwt. of saltpetre (nitrate of potash) is recommended as a sufficient dressing for an acre, 1¼ to 1½ cwt. of nitrate of soda is recommended for an equal area. It would, therefore, be desirable where nitrate of soda is applied to any large extent of land, either with oats or barley, to make a comparative trial on three equal portions of the same field, with 1, 1¼ and 1½ cwt. per acre, respectively.

In addition, therefore, to the experiments suggested in regard to wheat, with the view of determining—

1°. The absolute and relative efficacy of saltpetre and nitrate of soda on different varieties of the grain;

2°. The same on different varieties of soil;

3°. And under diversities of management,—as in the previous treatment of the land, &c.;

There may be added, in regard to oats and barley, another series of trial to determine—

4°. The relative effects of different proportions of the nitrate of soda, which is at present *supposed* to be specially beneficial to these kinds of grain. If any one be desirous of uniting this latter series with the former, it may be done thus—

Sulphate of Soda.	Nitrate of Soda, 1 cwt. per acre.	Saltpetre.
Nitrate of Soda, 1½ cwt.		Nitrate of Soda, 1¼ cwt.

The vacant half-acre being as before left for the purpose of comparison. Such an entire series might be made at the same time on a field of Tartary and of potato oats, and on two or more varieties of barley.

These top-dressings may be all sown broad-cast—on the wheat most conveniently when the seeds are sown in April or May, and on the barley and oats when the fields have become distinctly green.

I may be permitted to add, as inducements to practical men, to try one or more of these experiments in the accurate manner above described:

1°. That the result will be directly available and of immediate practical value on his own farm, to the person by whom they are carefully made. That they will be permanently useful to his landlord (if carefully recorded), ought to be an inducement to the latter to give every facility and encouragement to his tenant in making them.

2°. That, instead of involving expense and outlay, which in many instances may ill be spared, *they are sure in almost every case to do more than repay the cost of making them*, by the increased quantity or value of the produce obtained. Any of the series of experiments, on the scale suggested, may be made for five pounds, so that were the outlay all to be lost, the accurate knowledge obtained in reference to the general tillage of his land, would be worth more money to the holder of a farm of a hundred acres.

3°. I need scarcely add, as a further inducement, the additional interest which such experiments give to the practice of farming—and the means they afford of calling forth the intelligence of the agricultural population. The moment a man begins to make experiments under the guidance of an understood principle, from that moment he begins to think. To obtain materials for thought he will have recourse to books—and thus every new experiment he makes, will further stimulate and awaken his intellect and lead him to the acquisition of further knowledge. Does it require any thing more than this general awakening of the minds of the agricultural class, to advance the science of agriculture as surely and as rapidly as any of the other sciences, the practical application of which have led to those extraordinary developments of natural resources, which are the characteristic and the pride of our time?

III.—*Of Turnips.*

The raising of turnips is of such vast importance in the prevailing system of husbandry, that any improvement in the mode of culture must be of extensive and immediate benefit. Experiments so numerous and so varied have been made with this view, that it may almost seem superfluous in me now to make any further suggestions on the subject. But when experiments have been made with a view to one subject only, it often happens in all departments of natural science, that as new views are advanced, or more precise methods pointed out, it becomes necessary to repeat all our former experiments,—either for the purpose of testing the results they gave us, or of observing new phenomena to which our attention had not previously been directed.

I. Numerous experiments, for example, have been made upon the use of bones in the raising of turnips, but they have been chiefly directed to economical ends, and so far with the most satisfactory results. But among fifty intelligent and thinking practical men, and who all agree in regard to the profit to be derived from the use of bones with the turnip crop, how many will agree in regard to the mode in which they act—how few will be able to give a satisfactory reason for the opinion they entertain! The same is true of theoretical chemists, some attributing their effect more especially to the earthy matter, others to the gelatine they contain. Dry bones contain about two-thirds of their weight of earthy matter, the other third consisting chiefly of animal matter resembling glue. Of the earthy matter five-sixths consist of phosphate of lime and magnesia, and the rest chiefly of carbonate of lime. Thus a ton of bone dust will contain—

Animal matter	746 lbs.
Phosphate of lime, &c.	1245 lbs
Carbonate of lime, &c.	249 lbs.
	2240 lbs.

On which of these constituents does the efficacy of bones chiefly depend? Does it depend upon the animal matter? This opinion is in accordance with the following facts:—

1°. That in the Doncaster report it is said to be most effectual on calcareous soils,—for in the presence of lime all organic matter more rapidly decomposes.

2°. That horn shavings are a more powerful manure than bones,—since horn contains only one or two per cent. of earthy matter.*

3°. That before the introduction of crushed bones, the ashes of burned bones had long been employed to a small extent in agriculture, but have since fallen almost entirely into disuse.

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* This, I believe, is rather a matter of opinion than the result of a sufficient number of actual trials. Some trials made by Mr. Hawden (British Husbandry, I. p. 895) gave results very unfavourable to horn shavings.

4°. That old sheep skins cut up and laid in the drills, have been found to yield as good a crop of turnips and after-crop of corn, as the remainder of the field which was manured with bones.

5°. That "40 lbs. of bone dust are sufficient to supply three crops of wheat, clover, potatoes, turnips, &c., with phosphates,"* while one to two-thirds of a ton of bones, containing from 400 to 800 lbs. of phosphates, is the quantity usually applied to the land.

On the other hand, the quantity of animal matter present in a ton of bones (746 lbs.) is so small, and its decomposition so rapid during the growth of the turnips—while at the same time the effects of the bones are so lasting and so beneficial to the after-crop of corn—that many persons hesitate in considering the great excess of phosphates applied to the land, as really without any share of influence in the production of the crops.

Thus *Sprengel*, an authority of the very highest character, both in theoretical and practical agriculture, is persuaded that the phosphates are the sole fertilizing ingredients in bones, and he explains the want of success from the use of crushed bones in Mechlenburg and North Germany, on the supposition that the soils in those countries already contains a sufficient supply of phosphates, while in England generally they are deficient in these compounds.

Further, if the animal matter be the fertilizing agent in bones why are not they of equal efficacy on grass land as upon turnips?

With the view, therefore, of leading to some rational explanation of the relative effects of the several constituents of bones, it would be desirable to institute comparative experiments of the following kind—

1°. With half a ton of bones per acre.

2°. With three or four cwt. of horn shavings or *glue* per acre.

3°. With two cwt. of burned bones per acre.

4°. With six or seven cwt. of burned bones per acre.

The quantity of burned bones in No. 4 is that which is yielded by a ton of fresh bones; that in No. 3 is upwards of five times what should be taken up by the crops—as great part of what is added must be supposed to remain in the soil, while *some must be dissolved and carried off by the rains.*

The result of such experiments as these, if made accurately on different soils, will lead us sooner to the truth than whole volumes of theoretical discussion.

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* *Liebig*, p. 84. The acre here spoken of is the Hessian, about three-fifths of the English acre. The English, therefore, will require 66 lbs.

II. Nitrate of soda has also been applied with great benefit in the culture of turnips. Some experiments, exceedingly favourable in an economical point of view, have been made by Mr. Barclay, of Eastwick Park, Surrey,* who found that one cwt. per acre, drilled in with the seed, gave as great a return of Swedes as 15 bushels of bones with 15 of wood ashes per acre, and when the nitrate of soda was sown broadcast, from 20 to 25 per cent. more. In every part of the country, therefore, this substance ought to be tried. And as this nitrate is very soluble in water, and may therefore be readily carried off by the rain, and as that only which is within reach of the plant is of any avail, I would suggest that not more than one-fourth of the whole should be drilled in with the seed, for the purpose of *bringing away* the plant; and that after the thinning by the hoe, the rest should be strewed along the rows by the hand or by the drill. In this way the whole energy of the salt being expended where it is required, the greatest possible effect will be produced.

III. I have already stated the reasons which lead me to anticipate highly beneficial effects of vegetation from the use of sulphate of soda; I would suggest, therefore, a trial of this salt on the turnips also, at the same rate of one cwt. per acre, and applied in the way above recommended for the nitrate of soda. Of course the intelligent farmer will vary the proportions and mode of application of these substances, as his leisure or convenience permit, or as his better judgment may suggest to him.

The entire series of experiments on turnips, above suggested, may be represented as follows, adding two plots for different proportions of the nitrate and sulphate of soda:—

Burned bones, 2 cwt. per acre.	Nitrate of Soda, 1½ cwt. per acre.	Bone Dust, or Crushed Bones, 1 ton per acre.
Burned Bones, 6 or 7 cwt. per acre.	Sulphate of Soda, 1 cwt. per acre.	Horn shavings, or Glue, 7 or 8 cwt. per acre.
Unmanured.	Sulphate of Soda, 1½ cwt. per acre.	Nitrate of Soda. 1 cwt. per acre.

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* Journal of the English Agricultural Society. I. p.428.

Some of these experiments most of you may easily try. Those with the burned bones and horn shavings, which in this part of the country are less easy to be obtained, it is not to be expected that many of you will think of undertaking. I hope, however, that they will not be lost sight of by those who possess facilities for obtaining them in sufficient quantity to make a satisfactory experiment.

In many parts of the United States, gypsum is the universal fertilizer for every crop, and among the rest it is said to benefit turnips. The same opinion is entertained in Germany. I am not aware how far, in what way, or with what results, it has been applied to the turnip crop in this country. A simple mode of testing its efficacy, however, would be to strew it over the plants when in the rough leaf, on part of a field, the whole of which had been already manured in the ordinary way with fold-yard manure. The difference of produce would thus show its efficacy, in the given circumstances; and the experiment could be made effectually at the cost of a single cwt. of gypsum.

I have not included *rape dust* among the trials above suggested, though it is undoubtedly, under certain modes of management, a beneficial manure both to corn and turnip crops. There is also a diversity of opinion as to the cause of its fertilizing action, as well as a manifest difference in the effect of different samples of the dust on the same soil. Though, therefore, certain experiments which I may on a future occasion suggest, would undoubtedly throw light on the cause of the good qualities of this manure, yet as its action (taking different samples) is not *constant* on the same soil, results obtained with it cannot possess the same importance, either theoretical or practical, as those which are observed to follow from the use of bones and of saline substances, the composition of which is nearly invariable.

Many farmers, however, are in the habit of constantly using rape dust. If any of these could conveniently make experiments on the effect of different samples of the cake, from different kinds of seed, and from different oil mills, and would accurately note the results, they would perform an important service in preparing the way for that clear explanation of the cause of its fertilizing action, which is at present wanted,* and which experiment alone can discover to us.

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* Its good effects are generally attributed to the oil which is left in the seed, and its varying action to the different quantities of oil left in it by different crushers—I doubt, however, if the oil ought to be considered as more than a secondary cause of its beneficial action.

IV.—*Of Potatoes.*

1°. Nitrate of soda has been applied with great benefit to potatoes also. After the potatoes have been harrowed down and (hand) hoed, and the plants are four to six inches above the ground, it is applied by the hand round the stem of the plants, and the earth then set up by the plough. Mr. Turnbull, in Dumbartonshire, last year used in this way at the rate of 1½ to 2 cwt. per Scotch acre, (1¼ English acres,) and the produce exceeded that of the land to which no nitrate was applied, by 20 Scotch bolls to the Scotch acre.

2°. Applied in the same way there is every reason to believe that the sulphate of soda would have a highly beneficial effect also. I repeat my recommendation that this substance should be fairly tried with every crop, because it is a product of our own manufactories, which can be supplied in unlimited quantity, and without the chance of any material increase of cost; while the nitrate of soda is already in the hands of speculators, and within a short period has risen in the market to the extent of nearly one-third of its former price.

In *plastering* their potatoes, the Americans generally put in a spoonful of gypsum with every cutting—a similar method, if preferred, might be adopted with the nitrate and sulphate of soda, though the chance of loss by percolation through the soil, would, by this method, be in some degree increased. In Flanders, wood ashes and rape dust are frequently thrown in by the hand, when each cutting is introduced.

3°. I shall have occasion hereafter to recommend to the attention of the practical farmer, many waste materials of various kinds, thrown out from our manufactories, the application of which to useful purposes would be a great national benefit. In reference to the culture of potatoes, I will here bring under your notice the chloride of calcium, which is said to have been beneficially applied to various crops, but to potatoes especially, with surprising effect. Under the influence of this substance the sunflower and maize have grown to the height of 14 to 18 feet, and potatoes have attained the weight of 2 to 3 pounds.* In Germany, Sprengel also found it useful to potatoes.—(*Chemie für Landwirthe, I. p.* 635.)

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* The *Rohan*, a French variety of potato lately introduced into the United States—by the ordinary mode of culture—yields tubers, very many of which weigh 3 lbs. and many attain to the weight of 5 lbs. When perfectly ripe, it is said to be an excellent table potato, and to be best in the spring. —*Albany Cultivator, for March*, 1841.

Thousands of tons of chloride of calcium may every year be prepared from the waste materials which flow into the river Tyne, from the alkali works upon its banks. Thousands of gallons of the solution of this substance yearly run off from the works of Messrs. Allan & Co. at Heworth, and might be procured for little more than the expense of collecting. It is also contained largely, though mixed with other substances, in the mother liquor of the salt pans; and from the numerous salt works on the coast might readily be obtained for trial. When prepared in the dry state, this substance rapidly *deliquesces* and runs into a liquid. The most convenient way of applying it, therefore, would be in the state of solution—so largely diluted as to have only a slight taste—and by means of a watering cart so contrived as to allow it to flow on the tops of the ridges and young plants, by which unnecessary waste would be prevented.

Without knowing the strength of the solution likely to be obtained from the works, it is impossible to give any idea of the quantity of the chloride of calcium which ought to be employed; but 500 gallons per acre may safely be used, if the solution be so far diluted as to have only a decided taste of the substance.

The experiments here suggested, therefore, require four patches, as follows:—

Nitrate of Soda, 1 to 1½ cwt. per acre.	Sulphate of Soda, 1 to 1½ cwt. per acre.
Chloride of Calcium, 500 gallons per acre.	Manure only.

These experiments are supposed to be made in ground already prepared for the potato crop, by the usual quantity of manure. I think it not unlikely, however, that by planting the potato in the midst of the nitrate or sulphate (sprinkled over with dry soil) at the rate of half a cwt. per acre, and afterwards applying one cwt. per acre, when the plants are hoed, a crop might be obtained without the use of manure. Of course, such an experiment as this, though important to be made, should be tried cautiously, and on such a scale as to secure the experimenter from any serious loss.

In the above suggestions I have introduced nothing in regard to *mixed* manures—though where plants require for the supply of *all* their wants nine or ten different ingredients, of which the soil they grow in can perhaps yield in sufficient quantity only three or four, it is obvious that the very best consequences may follow from the employment of mixed manures. To this class belong common night-soil, urine, animalized carbon, *poudrette* (night-soil mixed with lime and gypsum), the *poudre vegetatif* (a mixture of soot and saltpetre), the *urate* (now manufactured in London), and many others.

The mode of preparing, and the special uses of these and other mixed manures, will be explained in the third part of these lectures, which will be devoted to the consideration of the nature and uses, and to the theory of the action of natural and artificial fertilizers. In the mean time it is desirable, in the first place, to obtain results from which the special action of each, when used *alone*, can be fairly deduced.

That these experiments may have their full value, it is indispensable that a measured portion of each field should be left without manure or dressing of any kind, in order that a true idea may be formed of the exact effect of each substance employed. Experiments are valuable to the practical man if they merely show the superiority of one species of manure over another, but they are insufficient to show how much each of them tends to increase the produce—or to enable us to arrive at a satisfactory explanation of the mode in which they severally act in promoting vegetation.

Among other important experiments lately published, to which the above observation is applicable, may be mentioned those of Mr. T. Waite, of Doncaster. The effects of nitrate of soda on his land were very striking, showing a remarkable increase of produce over bone dust, rape dust, or rotten fold-yard manure—but he does not seem to have determined the produce of the same land during the same season and *without manure*. We have, therefore, no term of comparison, by means of which we can ascertain the absolute or even the exact comparative effect of the different substances employed.

It has been well observed by Sir Humphry Davy, "that nothing is more wanting in agriculture than experiments in which *all the circumstances* are minutely and scientifically detailed, and that this art will advance in proportion as it becomes exact in its methods."* The above suggestions are submitted to practical men in the hope that they may assist in introducing such exact methods into our agricultural operations, and at the same time promote the theoretical advancement of the most important art of life.

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* Agricultural Chemistry, Lecture I.

Exact methods lead to theoretical discoveries, while these are no less certainly followed by important practical improvements.

No. II.

(See Lecture II. p. 44.)

In illustration of the effect of sudden alternations of temperature on vegetable substances, explained in a note subjoined to page 44, I quote with pleasure the following instructive letter from an ably conducted Monthly Journal published at Albany, in the State of New-York, under the title of the *Cultivator*. It is extracted from the Number for March last:—

"In regard to Irish potatoes, a still thinner covering of earth than the one just mentioned suffices with us to preserve them from rotting. Indeed, it would seem as if they could freeze and thaw several times, during the winter, without being destroyed, provided they are covered with earth all the time; for we often find them near the surface and perfectly sound, in the spring, when spading up the ground in which the crop had grown during the previous season. There they must have undergone freezing and thawing whenever the earth was in either state, as it often is to a much greater depth than the potato roots ever extend. Why should those roots always be destroyed when they freeze *above ground*, and not suffer equally when frozen *under ground*?

"The reason why potatoes, apples, &c., become soft, and rot when frozen and then thawed suddenly, uncovered and in open air, is the sudden thawing. You may put a heap of apples on the floor of a room, or other dry place, where they will freeze perfectly hard, and if covered close with any thing that will exclude the air, when the weather becomes warm enough to thaw, the apples will remain sound and uninjured, after they are thus closely thawed. The cover may be of the coarse tow of flax, or any article that will cover them close and exclude the air. So apples may be packed in a tight barrel, if full and headed up so as to exclude the air. They may be suffered to remain so in a garret, or any dry place where it freezes hard, and they will be found sound and free from injury, if the barrel remains tight till they are *thoroughly thawed*. It is the sudden thawing that causes the apples or other vegetables to become soft and rot.

"So if the fingers on your hand be frozen, and you expose them to sudden heat by warming them at the fire, and they suddenly thaw the flesh will mortify and slough off. But, if you freeze your fingers or other limbs, and put them in snow, and rub gently till they thaw,—or if put into a pail of water just drawn from the well, which will be less cold than your frozen fingers,—they will thaw slowly, and suffer but little injury.

"So during the early autumnal frosts in September, if the morning after the frost is cloudy, the frost will be slowly drawn from the frozen vegetables, and they will be uninjured; but if they receive the rays of the early and clear sun, they thaw so suddenly, that they will hang their heads and perish. If wet with water from the well, long enough to extract the frost before the sun shines on them, they do not suffer.

"Onions are a difficult root to keep in winter. If they are put in a cellar warm enough to save them from frost they will vegetate and be deteriorated. I put them in the warehouse, where they freeze as hard as if out of doors. If in a heap, I cover them close with some old clothes, or any thing that covers close, to exclude the air. The same if in boxes or casks. They freeze hard, but it does not appear to injure them for present use, if thawed by putting them into a pail of fresh-drawn water, to draw out the frost just before cooking them. Onions thus kept, will be in good condition in the spring, after thawing under cover from the air.

"I put parsneps, carrots, beets, &c., in boxes or casks, and then cover them with potatoes, which preserves them from drying."

In further illustration of this subject I need only recall to the recollection of the gardener the well known fact, that, when the winter frosts begin to set in, and his finest flowers to be nipped, those continue to blow the longest, on which the sun's rays fall latest in the day. Dahlias protected in this way will bloom occasionally for weeks, after those which regard the eastern sky are completely withered.

Professor Lindley has published a series of valuable observations on the effects of extreme cold upon plants. The general results of these observations are stated in his "*Theory of Horticulture*," p. 88. But the conclusions at which he has arrived are deduced from the appearance presented by the plant after it was *thawed*. He found the tissue more or less lacerated, the contents of the air and sap vessels intermingled, and the colouring matter and other secretions decomposed. He attributes the laceration to the freezing and consequent expansion of the juices, but this cannot be the necessary consequence of that freezing, since it does not appear, if the whole tuber or leaf be slowly thawed. I would explain the phenomena as follows:—

1°. When the leaf, fruit, or tuber freezes, the fluid portions slightly expand in becoming solid, but the air in the air vessels contracts in at least an equal degree, and thus allows a lateral expansion of the sap vessels sufficient to prevent lesion. When the temperature is slightly raised, the air expands but slightly, and ice is melted long before the gaseous substances reach their original bulk.

2°. But if the rays of the sun strike suddenly upon the leaf or fruit, the surface may at once be raised in temperature 30° or 40° F. The air will consequently expand suddenly, and before the sap is thawed may have distended and torn the vessels, and caused sap and air to be mutually intermingled.

3°. But the moment the sun's rays strike upon the green leaf, its chemical functions commence. It begins to absorb and decompose carbonic acid: and as in the frozen part of the leaf the circulation is not, and in consequence of the lesion cannot be established, the chemical action of the sun's rays must be expended upon the stagnant sap; and hence those changes not only in the sap *itself*, but even in the solid parts, which are seen to take place in the withered leaf.

4°. Though not in a state of growth, the tuber of the potato contains the living principle, and there must be such a circulation going on in its interior as to maintain an approximate equilibrium of temperature throughout its substance. A sudden thawing of the exterior, will, as in the leaf, expand the air before the circulation can be established throughout the frozen mass. The solid, fluid and aeriform substances which nature has separated and set apart from each other, will thus all be intermingled, and from their mutual action, those chemical changes of which we know the starch of the potato to be susceptible, will speedily ensue;—in other words, the potato will rot.

The practical applications of these views are numerous. If a sudden frost come on,—protect your delicate flowers in the early morning from the rays of the approaching sun, and cover with straw or earth the potatoes which have been left overnight in the field.

No. III.

RESULTS OF EXPERIMENTS ON PRACTICAL AGRICULTURE DURING THE SPRING AND SUMMER OF 1841.

See Appendix, No. I, and Lectures VIII. and IX.

In a previous article inserted in this Appendix, and which was published early in the present spring (April, 1841,) I ventured to offer to the practical agriculturist some suggestions in regard to the *experimental use* of certain unmixed manures. From the results of these experiments, which I was quite sure some of the many zealous agriculturists of the day would be induced to undertake after the manner, and with the precautions, I had pointed out, I anticipated a two-fold advantage. In the first place, that important practical benefits to the agriculture of certain districts would be derived from them, and secondly, that interesting and important light would be thrown by them on many parts of agricultural theory. It is by experiment that all the remarkable results—theoretical as well as practical—of modern chemistry have been arrived at; but by experiments cautiously made, frequently repeated, and logically reasoned from. The proceedings of the practical farmer are a continued course of experimental trials, and to convert him into an experimental philosopher, and to lead him to philosophical results, it is necessary only that his experiments should be made *with a constant reference to weight and measure*, and should be repeated under varied and carefully noted conditions—and that he should be taught to draw from them no conclusions more general than they really justify.

The following results of experiments made during the past summer confirm all my anticipations. Though necessarily somewhat limited, and local in their nature, they, nevertheless, present on the whole a beautiful illustration of what we have yet to expect from a continuation of such experimental researches, conducted in so skilful a manner. I need not especially commend the experiments of Mr. Fleming; for I can scarcely, I think, render a better service to practical agriculture than by placing all of them in the hands of practical men, and earnestly commanding them to their careful consideration and imitation.

I. Experiments made near Aske Hall, on the property of the Earl of Zetland.

HALF AN ACRE.

Soot—put on 24th May—10 bushels cost 6s. 6d.

Weight of grass when mown, 3 tons 16 cwt.
Weight when made into hay, 1 " 15 "

HALF AN ACRE.

Salt—put on 24th May—3 bushels cost 6s. 6d.

Weight of grass when mown, 3 tons 19 cwt.
Weight when made into hay, 1 " 16 "

HALF AN ACRE.

No Manure.

Weight of grass when mown, 3 tons 12 cwt.
Weight when made into hay, 1 " 6 "

HALF AN ACRE.

Nitrate of Soda—put on 24th May. 4 stones cost 11s.

Weight of grass when mown, 4 tons 10 cwt.
Weight when made into hay, 1 " 12 "

HALF AN ACRE.

Sulphate of Soda (in crystals)—put on 24th May—4 stones cost 10s.

Weight of grass when mown, 3 tons 3 cwt.
Weight when made into hay, 1 " 9 "

HALF AN ACRE.

Sulphuric Acid—⅓ put on 26th May, ⅓ put on 7th June, ⅓ put on 11th June—15lbs. cost 5s.

Weight of grass when mown, 3 tons 4 cwt.
Weight when made into hay, 1 " 6 "

General Results per imperial acre.

	Quantity applied.	Cost.	Produce when cut.	Produce in hay.	Hay from 100 of grass.	Increase in hay.
			tons cwt.	tons cwt.		tons cwt.
Common Salt .	6 bshls.	13s.	7 18	3 12	52	1 0
Soot . .	20 "	13s.	7 12	3 10	53	0 18
Nitrate of Soda .	112 lbs.	22s.	9 0	3 4	36	0 12
Sulphate of Soda	112 "	20s.	6 6	2 18	46	0 6
Sulphuric Acid .	30 "	5s.	6 8	2 12	40	0 0
No manure .	—	—	7 4	2 12	36	— —

N. B. The cost of the manure does not include the expense of laying it on.

Mr. Turner, his lordship's agent, thus writes:—

"The plan I followed in putting on the different manures, and the quantities used, accorded as nearly as I could manage it, with the directions given in your published lectures.

"The field on which the experiments were tried is situate in a high, bleak climate, and consists of a thin light soil, upon a bad subsoil of barren clay resting upon limestone. It had been completely exhausted by a succession of white crops, and was full of weeds and quickens. I had it well ploughed, and took a crop of drilled turnips fairly, but not extravagantly, manured. The crop was a poor one. I ploughed the land as soon as the turnips could be got off. Drained it; and in the spring worked it very fine. The following August I sowed it away with grass seeds without a crop. The seeds came up beautifully, and were the admiration of all who saw them, keeping a deep green through the winter, and beginning to grow early in the spring; and it was on this crop that the experiment was tried early in the succeeding summer.

"I need scarcely remark, that the crop of grass for such land was enormous, and has fully repaid the money expended upon it, with the exception of draining, and in two or three years I have no doubt but it will repay this also."

Remarks.—On comparing the effect of these several top-dressings as indicated by the results above stated, the reader will be struck with the extraordinary increase caused by the addition of common salt. I have in the text (Lecture IX., p. 279) indicated a principle which may serve to explain *in some measure* both the localities in which the use of common salt may be expected to be beneficial, and the reason why in many parts of our island the employment of this substance has not been attended by any large measure of success. The position of the land experimented upon by Mr. Turner, is such as to lead us to expect it to be improved by common salt, according to the views there stated.

The nitrate of soda produced less effect than either the common salt or the soot, but it gave an increase which was double of that yielded by the sulphate of soda. The latter salt, however, was applied in the state of crystals, which contain 55 per cent. of water, so that less than one-half of that weight *of dry* salt was used, which was recommended in the suggestions I offered for the employment of this substance in practical agriculture. At the same time the price paid by Mr. Turner for this salt was *four times* as great as it ought to have been. Any quantity of the *dry* sulphate of soda may be procured at 10s. a cwt.*

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* By addressing a note to Messrs. Allen & Co., Heworth Alkali Works, Newcastle, who forward it in casks to all parts of the country.

The most valuable practical suggestion to be derived from these experiments is certainly this—that a liberal use of common salt is likely to increase in a great degree the produce of grass in the locality where they were made, and on the same kind of soil. This valuable discovery will far more than repay the expense and trouble of the entire series of experiments. No application can be so cheap as this, *so long as it succeeds.* At the same time a mixture of the other substances—the nitrate and the sulphate, which were partially successful—might possibly prove still more efficacious on the grass, and might be expected even to ameliorate the condition of the land for the further production of white crops. In a future part of this Appendix I intend to offer some suggestions in regard to the *kind* and *quantity* of the ingredients which may, with probable advantage, enter into the constitution of these *mixed manures.*

I have calculated and introduced into Mr. Turner's table an additional column, exhibiting the weight of hay yielded by 100 lbs. of grass, with the view of showing the relative succulence of the several crops when cut. As a general rule, the weight of dry hay does not exceed one-fourth of the weight of the grass when cut. In the experiments of Mr. Turner, however, the weight of hay in every case was much beyond this quantity—the most succulent crop, that to which no dressing was applied, yielding 36 per cent. of hay. This general result may have been partly due to the state of ripeness in which all the grasses were cut, while the greater produce of hay from the dressed portions may indicate the relative ripeness, and therefore dryness, of each when cut down.

It is evident, therefore, that the relative values of crops of grass or clover are not to be judged of by the several weights when green, but by the weights of the dry hay. This is further confirmed by the results of an experiment with nitrate of soda, communicated to me by Mr. Carruthers, of Warmonbie, near Annan, in which the relative weights of hay obtained were *much more in favour* of the use of the nitrate than the several weights of grass yielded by the dressed and undressed portions of the field. On the contrary, from a field on Oliver Farm, near Richmond, Mr. Sivers informs me, that the weight of hay was *much less in favour** of the use of the nitrate of soda than the relative weights of grass. In all cases, therefore, the weight of the dry crops obtained by different methods should be compared with each other, as the safest test of the relative merits of the several modes of procedure by which they have respectively been raised.

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* In Mr. Sivers' experiments, 100 square yards, *nitrated*, gave 68 stones of hay, unnitrated 52 stones, but when dry were reduced to 12 stones each. How very much more succulent these grasses were than those of Mr. Turner!

II. Experiments made at Erskine, on the property of Lord Blantyre.

I insert the clear and well-digested statement of his Lordship's agent without alteration :—

"*Freeland, Erskine, by Old Kilpatrick, Glasgow*
29th July, 1841.

"Sir—Agreeably to Lord Blantyre's instructions I send you a copy of the results of some experiments with manures on young grass for hay, undertaken on two separate pieces of land—the one a very good light soil (subsoil gravel) ; the other stiff clay soil with a clay subsoil. The manures were applied on 1st May, the hay cut on the 1st and weighed on the 19th July current; the extent of each plot one-twentieth of an imperial acre. From the small extent of each plot it will be evident that the results cannot be exactly depended on, farther than as a general result; because, in so small a portion of land the least variation in the soil or crop naturally will affect the results very materially ; still, on the whole, I am of opinion that the experiment gives the comparative view of the value of the different manures used pretty nearly.

"One thing has astonished us with regard to soda (nitrate). On all the fields I have observed it sown on, the part dressed has a much greater vigour of aftermath than where no nitrate of soda was given: showing that this manure is not so evanescent as was generally supposed.

"I am, Sir, your most obedient servant,
"Jas. Wilson."

Experiments with Manures as a top-dressing for Hay, at Erskine, 1841.

The Dressings were applied 1st May, the Grass cut 1st July, and the Hay weighed 19th July.

No. of Plots.	APPLICATION.	I. Exp.—good light soil, subs. gravel.										II. Exp.—clay soil, subsoil clay.									
	Manures used, and quantities applied, to each plot of 1-20th of an acre.	Weight on 1-20th of an acre in pounds.	Increased weight on 1-20th of an acre.	Total produce per Imperial Acre				Total additional weight per Imperial Acre.				Weight on 1-20th of an acre in pounds.	Increased weight on 1-20th of an acre.	Total produce per Imperial Acre.				Total additional weight. per Imperial Acre.			
				ts.	cwt.	qrs.	lbs.	ts.	cwt.	qrs.	lbs.			ts.	cwt.	qrs.	lbs.	ts.	cwt.	qrs.	lbs.
1	1lb. sulphuric acid,diluted in 47 galls. water, . . .	271	44	2	8	1	16	—	7	3	12	256	26	2	5	2	24	—	4	2	16
2	6lbs. saltpetre (nitrate of potash)	322	95	2	17	2	0	—	16	3	24	286	56	2	11	0	8	—	10	0	0
3	6lbs. nitrate of soda, . .	339	112	3	0	2	4	1	0	0	0	282	52	11	0	1	12	—	9	1	4
4	6lbs. sulphate of soda (in crystals)	292	65	2	12	0	16	—	11	2	12	232	2	2	1	1	20	—	0	1	12
5	17lbs. gypsum, . . .	254	27	2	5	1	12	—	4	3	8	240	10	2	2	3	12	—	1	3	4
6	1 bush. wood charcoal (pounded)	277	50	2	9	1	24	—	8	3	20	257	27	2	5	3	16	—	4	3	8
7	¼ bush. common salt, 25 galls. water, . . .	294	67	2	12	2	0	—	11	3	24	269	39	2	8	0	4	—	6	3	24
8	1 gallon ammoniacal liquor, 47 galls. water, . .	277	50	2	9	1	24	—	8	3	20	201	—	1	15	3	16	—	—	—	—
9	No application, . .	227	—	2	0	2	4	—	—	—	—	230	—	2	1	0	8	—	—	—	—

Remarks.—It will be observed in these experiments, that the saltpetre and nitrate of soda produced *nearly* an equal increase on both kinds of soil, the nitrate of soda having the greater effect on the light, the nitrate of potash on the heavy soil. Next to these on the light soil are the common salt and sulphate of soda, though on the heavy soil the common salt had the better effect of the two. It is to be observed, however, that in this case the sulphate was used in crystals, and therefore only in half the quantity recommended. Had twice the quantity been employed upon the *light* soil the produce might have equalled that from the nitrates.

It is a singular illustration, however, of the necessity of applying different substances to different soils—that so far as this experiment is to be depended upon, the sulphate of soda almost entirely failed on the heavy land.

The most valuable practical deduction from these experiments also, is, that on both of the soils in question, the grass land *in its present condition*, may be salted to advantage. At the same time, it appears probable that on the light soil the increased produce would amply repay the cost of applying either nitrate or sulphate of soda at the rate of 120 lbs. per acre—the latter being in its dry or uncrystallized state.

The effect, generally, of all the dressings is strikingly greater on the light soil—a fact which speaks strongly in favor of the adoption of any of those methods by which the openness and friability of the land has been found to be permanently promoted. On the stiff soil, even the ammonia, by some deemed so vitally necessary to vegetation, appears to have produced no sensible alteration.

III. Experiments made under the immediate superintendence of W. Fleming, Esq., of Barochan, near Paisley, and on his own property. The statement is drawn up by Mr. Fleming himself.

1.—*Experiments on Hay with Nitrate and Sulphate of Soda and with Gypsum.*

On Covenlea the dressings were applied on the 22nd of April, and the hay cut on the 2nd of July; on the other fields the nitrate and gypsum were applied on the 12th of April, and the hay cut on the 9th of July.

No.	Field.	Description of Dressing.	Rate per imp. Rood.	Weight per Rood, green.	Weight when stack'd
1	Covenlea.	Nothing.	—	3361 lbs.	1120 lbs.
2	Do.	Nitrate of Soda.	40 lbs.	4907 ''	1636 ''
3	Do.	Sulphate of Soda.	40 lbs.	3966 ''	1322 ''
4	Do.	Gypsum.	10 lbs.	3831 ''	1277 ''
1	Crook's High.	Nothing.	—	4436 ''	1478 ''
2	Do.	Nitrate of Soda.	40. lbs.	4999 ''	1666 ''
1	Crook's Low.	Nothing.	—	2185 ''	728 ''
2	Do.	Nitrate of Soda.	40 lbs.	3764 ''	1254 ''
3	Do.	Gypsum.	80 lbs.	3110 ''	1036 ''

Character of the soil.—Nos. 1, 2, 3, and 4, were good sharp soil on *rotten* rock, (decayed trap,) all as near as possible the same description of land, drained, and lying together. Nos. 1 and 2, Crook's High, stiff clay, drained; the hay was after wheat. Nos. 1, 2, and 3, Crook's Low, light clay-loam, drained; the hay was after barley.

N. B. The above is the average of trials in three parts of the Covenlea field; a small portion of moss was also sown with nitrate of soda, in the low part of the same field, but no benefit was observable, beyond the usual dark green colour which appeared about ten days after the application. The sulphate of soda, although evidently beneficial, does not produce the dark green colour. In the Crook's fields the effect of nitrate of soda in producing the dark green colour was as remarkable as in the Covenlea field. The Gypsum on both fields seems to have had a good effect, particularly on the aftermath clover.

REMARKS.—In these experiments also the sulphate of soda was used in only half the quantity recommended. By referring to the prices paid by Mr. Fleming, it will appear that the use of sulphate of soda gave an increase of 200 lbs. of hay for 1s. 9d. (or 500 lbs. for 4s. 5d.), while the nitrate of soda gave an increase of 516 lbs. for 7s. 10d.; so that, though the actual increase of hay per rood was considerably less by the use of the sulphate, yet that increase was obtained at little more than half the cost of the same weight of increase derived from the nitrate. A similar remark applies to the gypsum, so that these experiments give ample encouragement for the application of both these substances in somewhat large quantity to succeeding crops, on the same land.

2.—*Experiments on Winter Rye, dressed with Nitrate of Soda, Lime with Potash, Sulphate of Soda, and Muriate of Ammonia (Sal Ammoniac.)*

The applications were made on the 14th of April, the grain was cut on the 9th of August, and thrashed on the 25th.

No.	Field.	Description of Dressing.	Rate per rood imperial.	Weight of Grain. per rood.	Weight of Straw. per rood.	Bushels. per rood.
1	Garden Plot.	Nothing.	—	160 lbs.	1024 lbs.	3½
2	Do.	Nitrate of Soda.	40 lbs.	336 "	1664 "	6½
3	Do.	Lime and Potash.	40 "	272 "	1344 "	5¼
4	Do.	Sulphate of Soda.	40 "	224 "	1152 "	4¼
5	Do.	Mur. of Ammonia.	5 "	232 "	1216 "	4¾

Character of the Soil.—Tilly clay, which had been trenched, and in potatoes the year before. The Rye was sown on their being lifted in October, 1840.

N. B. As early as the end of April the effects of the nitrate of soda were very apparent from the dark green colour produced, and broad leaves, and after it was ripe the heads were longer than any of the others; but it was so strong that it was laid a month before it was cut; none of the others were laid. Every application seems to have done good, by increasing the produce. The potash and lime was made by slacking quick-lime and sand with a solution of potash, and allowing them to lie together for a month. As much was used as contained 1 lb. of carbonate of potash to the pole.

REMARKS.—From these experiments, it appears that besides the proportionate increase of straw, that of grain was

From nitrate of soda,	12 bushels	for 31s. 0d., or 2s. 9d. pr. bush.	
" lime and potash,	7 "	for 33s. 6d., or 4s. 9d.	"
" sulphate of soda,	3 "	for 7s. 0d., or 2s. 4d.	"
" sal-ammoniac,	5 "	for 10s. 9d., or 2s. 2d.	"

Although, therefore, the total increase by the employment of sulphate of soda and muriate of ammonia, in the proportions actually put on, was not so great as by the use of the other two dressings, yet this increase was obtained at a considerably less cost per bushel. The lime and potash, though producing an important effect, will probably not yield a remunerating return with this crop *on this soil*, while the results hold out a fair inducement for the trial of the last two dressings in larger and varied proportions.

The five samples weighed respectively,—45⅗, 51¾, 51⅘, 52⅗, and 48⅕ lbs. per bushel, so that, while on all the dressed plots the grain was heavier than on the undressed, that which was dressed with sulphate of soda was considerably the heaviest.

3.—*Experiments on Wheat field, Crook's (crop, 1841.)*

The applications were all made on the 13th of April, and the crop was reaped on the 2nd of September.

No.	Description of Top-dressing	Rate per Scotch acre.	Weight of produce of Grain of 1-8th acre	Weight of Grain per bshl.	Weight of total produce, when cut, of 1-8th an acre.
1	Nitrate of Soda	160 lbs.	209 lbs.	63 lbs.	9,500 lbs.
2	Potash and Lime.	160 lbs. 40 bush.	210 "	62 "	8,930 "
3	Common Salt.	160 lbs.	249 "	62 "	12,540 "
4	Mur. Ammonia	20 lbs.	208 "	62 "	8,360 "
5	Nitrate of Soda and Gypsum.	80 lbs. 160 bush.	214 "	62 "	8,620 "
6	Nitrate of Soda and Rape-dust.	80 lbs. 5 cwt.	240 "	62½"	11,970 "
7	Mur. Ammonia and Lime.	20 lbs. 40 bush.	230 "	63 "	9,500 "
8	Common Salt and Lime.	28 lbs. 80 bush.	200 "	63½"	8,740 "
9	Nothing.	—	190 "	61 "	8,050 "

Character of the Soil.—The land was heavy loam, and of as nearly as possible the same quality. It had been in potatoes, and the wheat was sown when they were lifted in October, 1840,

The produce of ⅛th of a Scotch acre, thrashed and weighed and well cleaned, gave an *average* of from 32 to 33 bushels of 61 lbs. each per Scotch acre of grain.

REMARKS.—This table presents us with two remarkable results,—that obtained by the use of common salt, and that from a mixture of soda and rape-dust. Thus, exclusive of the straw,—

Nitrate of soda alone	gave 152 lbs. of wheat for 31s., or 12s. 2d. per bushel;
Nitrate with rape-dust	gave 400 lbs. of wheat for 43s. 6d., or 6s. 9d. per bushel;

Common salt . . . . } gave 472 lbs of wheat for 3s. 6d., or 6d. per bushel.

The increased produce, by the use of common salt, is by far the most valuable result to Mr. Fleming in an economical point of view, and plainly indicates the kind of application he can most profitably make—to his wheat crops at least—on land similar to the above, and in the district where he resides.

Neither the nitrate of soda nor the mixture of this salt with rape-dust, gave such an increase as to repay their own cost, unless when corn is very high. It is interesting, however, to observe that the mixture with rape-dust gave so large an increase, though the value of this particular experiment is lessened by the absence of any trial with rape-dust alone, by which the effect of each of the ingredients ought to be judged of. I have reckoned the rape-dust at £7 a ton, so that 5 cwt. would cost 28s., and we know that a top-dressing of this substance alone, in a somewhat larger quantity, gives a remunerating return in many of our wheat lands.

Mr. Outhwaite, of Banesse, in the North Riding of Yorkshire, a skilful and enterprising practical farmer, who has for some years been using rape-dust over a great breadth of his wheat crops, has favoured me with the result of one of his more accurate trials on spring wheat, made during the past season. The wheat was sown after turnips taken off in April, and part of the field was dressed with rape-dust at the rate of 5¾ cwt. (or at £7 a ton, of 40s.), per acre. The produce of the dusted portion was 39 bushels, and of the undusted 29 bushels per acre, and the increase of straw was one-fifth of the whole. Both samples were of equal weight, and sold at the same price,—8s. 3d. per bushel. In this experiment the increased 10 bushels cost 40s., or 4s. per bushel, giving, on a large breadth of land, a handsome remuneration.

These results will, I trust, encourage others to make trials similar to those of Mr. Fleming and Mr. Outhwaite; while these gentlemen will, doubtless, be induced each to try that application which has succeeded so well in the other's hands. It might be useful as well as interesting to compare the produce of four plots arranged and dressed as follows:—

Common Salt.	Rape-dust.	Common Salt and Rape-dust.	Nothing.

4.—*Experiments on Early Potatoes*, 1841.

All were dunged in the usual manner with farm-yard manure, at the rate of about 30 cubic yards per acre. The potatoes were all planted on the 25th of March on the same *heavy black soil.* The several dressings were appled on the 20th of May, and the potatoes were all lifted on the 28th of September.

No.	Description of Top-dressing.	Rate per imp. acre.	Produce per imp. acre.	Weight of Produce of 18 yards drill.	
1	Nothing.	—	66 bolls.	77 lbs.	*Note.*—The peck is 35 lbs. weight, and 16 make a boll or 5 cwt.
2	Nitrate of Soda.	160 lbs.	80 "	93 "	
3	Sulphate of Soda	200 "	73 "	86 "	
3	Do. & Nitr. of Soda.	200 "	107 "	124 "	

This break of ground consists of a piece of poor clay mixed with moss, about 9 inches deep; subsoil a very stiff blue till. The dung was old from the farm-yard, about the ordinary quantity (30 cubic yards per acre) spread upon the land, and dug in. The potatoes were drilled in with the hoe; as the ground was wet the plants came up but weak. The nitrate of soda was sown before the other top-dressings, and had remarkably quick effect, as it showed the third night after being sown. The sulphate of soda does not occasion the dark green colour which is seen upon the potatoes after the dressing of the nitrate, but there is not the smallest doubt of its beneficial effects, although not in so great a degree as the nitrate. The mixture which is composed of ⅔ds of sulphate of soda and ⅓rd of nitrate, has a wonderful effect in strengthening the growth (which it keeps longer than with nitrate alone), and the mixture has the same effect in producing the dark green colour as the nitrate alone.

REMARKS.—That a *mixture* of substances is likely to be more efficacious as a dressing, than the application of one substance alone, except in peculiar circumstances, is consistent not only with long practical experience—for how many substances are mixed together in farm-yard manure?—but also with the theoretical principles laid down in the text.* These experiments upon potatoes show that this crop upon Mr. Fleming's land was benefitted by both nitrate and sulphate of soda, but in a vastly greater degree by a mixture of the two. And I might consider my suggestions in regard to the employment of sulphate of soda as a manure, to have been of no mean use in practical agriculture, had it led to nothing else than to this happy mixture of Mr. Fleming.

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* See Lectures IX. and X.

I have received also from Mr. Fleming's gardener (Mr. Alexander Gardiner) a very well digested and well drawn up paper, detailing numerous experiments made by himself during the past summer. Among these is one upon the use of this same mixture upon the potato crop, which I shall quote in his own words :—

" April 26th.—Planted potatoes of the red Don variety, soil a mellow loam, two feet deep, subsoil yellow till. Farm-yard dung was trenched in some days before planting, at the rate of 40 cubic yards per acre ; sets drilled in with the hoe. Plants came up very regular, and were top-dressed with a mixture of ⅔ sulphate and ⅓ nitrate of soda on June 2nd, at the rate of 2 cwt. per acre. They grew very strong after this application. *Stems six and seven feet in length*, dark green, and the produce, when lifted in October, was 16 Renfrewshire pecks of 35 lbs. each per Scotch fall of potatoes fit for market."

This produce is equal, I believe, to about 26 tons per Scotch, or 21 tons per imperial acre, about equal to that of Mr. Fleming with the same mixture. And what an amazing luxuriance of vegetation to yield at once stems 7 feet in length and upwards of 20 tons of tubers per acre !

Those who are the most skeptical in regard to the benefits to be derived from agricultural experiments, when well conducted, will scarcely question the importance of this result—the most backward in making experiments will be anxious to repeat this upon his *own* potatoes. The cost of the mixture to be applied in the quantity used by Mr. Fleming is as follows :—

		s.	d.
Sulphate of Soda	75 lbs. *dry* at 10s. per cwt. or 150 lbs. in crystals at 5s. . . .	6	9
Nitrate of Soda . .	75 lbs. at 22s.	14	9
		21	6

The return for this 21s. 6d. was in each of the above cases upwards of 8 tons of potatoes.

I may here mention two other interesting experiments of Mr. Gardiner, in which he tried the effect of sal-ammoniac upon his potato crop,—

1°. In the one he mixed sal-ammoniac, previously dissolved in water, in the proportion of 1 lb. to each cubic yard of a compost formed from the refuse of the garden, and planted early potatoes with it at the rate of 35 cubic yards per acre. The produce was one sixth more than when no ammonia was used. The variety of potato was Taylor's forty-fold, the soil moss and clay. The cost of this application was 19s. per acre.

2°. Sal-ammoniac, dissolved in water, was sprinkled on moss or peat earth, at the rate of 20 lbs. to a ton of earth, and, after strewing a little lime at the botton of the drills, this mixture was put in at the rate of 2 tons per acre. The potatoes were 14 days later in coming through the ground than the same variety planted with farm-yard manure. They were strong in the stem, of a dark green colour, and equal, in point of produce, to the others. The variety of potato was the Irish apple, the soil a very light brown loam, of that description locally named deaf.

I may observe on this latter experiment, that the application is not so simple as it appears. The lime would decompose the sal-ammoniac, and form *chloride of calcium*, while ammonia would be liberated. The effect, therefore, may be partially due to both. It will be recollected that in a previous part of this Appendix I suggested the trial of this chloride of calcium as a top-dressing for various crops.]

5.—*Experiments on Moss-Oats, sown about* 1*st May*, 1841, *top-dresses* 25*th June.*

No.	Top-dressing per pole (imperial).
1	Nothing.
2	Bones dissolved in sulphuric acid and nitrate of soda ¾ lb.
3	Sulphate of soda ½ lb., bone dust ½ peck.
4	Potash 1 lb., lime and bone dust ½ peck.
5	Chloride of calcium 1 lb., bones ¼ peck.
6	Lime, potash, and chloride of calcium, ½ lb. each.
7	Potash and lime, nitrate, and bones, ½ lb. each.

Character of the Soil.—Moss 4 feet to clay. No. 2 the best crop and heaviest grain (not thrashed). Nos. 3, 4, and 5 not so good as No. 2, but all much better than Nos. 1 or 6. No. 6 the worst—not better than No 1. No. 7 very good—next to No. 2.

"These top-dressings were applied on the 5th of June, and by the 24th there was a striking improvement, especially on No. 2 and No. 7. It was quite visible in greater strength and evenness of crop. One or two of the others also showed improvement, but not so visibly as to merit particular notice. I examined them from time to time, and at different dates: the appearances much the same as noticed upon June 24th. I again examined them a few days before they were cut, when I was much satisfied with No. 2; the straw appeared to me as stiff and shining, and the ear as well filled, as if it had been grown upon stiff loam, and I *consider the same dressing, applied to grain crops upon moss, will insure a good crop of well-filled oats.* No. 7 was nearly as good, but the want of the bones being dissolved was a drawback. However, I consider the two merit the expense of another trial."

REMARKS.—These experiments of Mr. Fleming on moss oats may be considered as affording another illustration of the benefits which are yet to accrue to practical agriculture from the suggestions of natural science. It is well known to those who have directed their attention to the reclaiming of peat lands, that the crops of oats raised on such land yield abundance of straw, but that the ear is small and badly filled. It is also well known that *claying* such lands is an almost unfailing remedy for this defect in the ear, as well as for the less important one which is also observed in the straw. My friend, Mr. Alexander, of South Bar, a neighbour of Mr. Fleming, and, like him, extensively engaged in the improvement of peat lands, finding, as most other persons have, that in some localities the claying of his land was very expensive,* conceived the idea that some chemical application might be made to this soil, which would supply what the defective oat plants required, and thus supersede the necessity of *claying*. He was pleased to communicate this opinion to me—stating the defect in the crop, and asking a chemical remedy. Looking chiefly to what was evidently required by the ear, I suggested a trial of various mixtures, in all of which,—from an idea that phosphates, among other substances, might be necessary to *complete* the ear—bone-dust form a necessary part. The result of these suggestions is seen in the above experiments of Mr. Fleming. They have been varied and improved upon, as Mr. Fleming's united chemical knowledge and practical skill enabled him to do, and as *first* results on a new field of research, Nos. 2 and 7 may be considered as highly encouraging, if not, indeed, eminently successful. Too much confidence, however, must not be placed on the effects observed in one or two instances; yet I hope those above stated are such as will induce others to repeat the experiments with equal care, in order that another year, affording us more numerous results, may enable us to base our conclusions upon a larger experience.

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* Mr. Garden, of Glenae House, near Dumfries, a gentleman to whom, though personally unknown, I am indebted for many valuable communications, informs me that, in improving his porous peat lands, he has found it necessary to lay on a coating of clay six inches thick, at an expense of £15 an acre. A coating of two or three inches on *their* peat, he says, sinks down, and in a few years descends beyond the reach of the plough, and hence it is more economical to lay on at once an entire soil of six inches.

6.—*Experiments upon Oats top-dressed with Sulphate and Nitrate of Soda* (*lower end of Barn Park.*)

"The first was sown on the 11th May, viz., 3 ridges with sulphate of soda, at the rate of 1½ cwt. per acre. This was examined from time to time, but there appeared to be little, if any, difference from the general crop (it has not yet been thrashed.) Next, 3 ridges were sown with nitrate of soda, at the rate of 80 lbs. per acre. This made a little alteration both in colour and strength, but it was too little to make a very decided difference. Also, alongside of the last-mentioned, a piece was dressed with a mixture of sulphate and nitrate of soda, in the proportion of ⅔rds of the former to ⅓rd of the latter. This immediately took the lead of the others both in colour and strength, so much so, that by May 27th it could be seen from a distance. Many examinations were made of them all during the season, and this always appeared the best. A few days before it was cut, it showed the largest and best filled ear. There was a piece of yellow-coloured earth at the bottom of the field, showing the presence of iron, upon which was sown potash and lime. The plant was yellow and sickly-looking, but immediately after application it acquired a dark green colour, and became vigorous, and yielded a crop at least equal to any in the field. There were some other dressings put on other ridges of this field, but it was dry weather directly after they were sown, and the crop was too far forward before they began to take effect to say any thing decided about them. By mistake there were two varieties of oats sown upon the field, which prevented the experiments being so decided, as the dressings were put on indiscriminately upon the land before it was known."

REMARKS.—The only remark I need make upon these experiments is, to suggest to my readers that, by repeating the above trials upon oats with Mr. Fleming's *mixtures*, they may not only benefit their own crops, but may also aid materially in the advancement of practical agricultural knowledge.

7.—*On the effect of Sulphate of Soda applied as a top-dressing to Beans and Pease.*

"The first dressing was applied the 4th of May, on some beans on a border in the garden; the drills that were dressed quickly took the lead of the others. There was no alteration of colour, but greater strength, and it *tillered wonderfully.* There were five or six stems from every seed sown, and the pods were larger and more numerous, and the beans in the pods a great deal larger than the same variety undressed. It was also put upon some of the ridges of the beans in the field, and with the same effect, and gave a very large crop (not yet thrashed.)

"Upon pease in the garden it appeared to add little, if any thing, to the strength of straw, but those that were dressed had a far greater number of pods, and those better filled, and the pease of a better flavour, and *it seems a valuable dressing for all leguminous crops.* When sown in the drills along with the pease, it nearly killed every one of them, while the same quantity, put on as a top-dressing to some drills next to them (where the pease were two inches high,) did no injury."

Remarks.—The testimony of Mr. Fleming to the value of sulphate of soda as a dressing for leguminous crops, is very valuable and satisfactory. We may hope that next year will furnish us with experiments, *all* the results of which shall have been so carefully ascertained, as to enable us to decide upon the economical value of this sulphate as a manure, by a comparison of the amount of increase in the crop, with the cost of the application.

8.—*On Nitrate of Soda as a top-dressing to Gooseberry and Currant bushes.*

"It was applied April 14th, at about the rate of ½ cwt. per acre, or ¼ lb. per bush. It had the effect, in the course of a week, of producing on the bushes a dark green colour and broader leaves, and the fruit set better and more plentifully, especially on some red currants that had borne little for two years. These set their fruit well, and yielded double their former produce. The dressed bushes kept the lead in strength and vigor all the season, and now, when the undressed bushes have lost their leaves, the others are quite green."

9.—"Many experiments were tried in the garden on turnips, by top-dressing with nitrate of soda, but with no perceptible effect.

However, the Swedish and red-top yellow, in a field of rather stiff soil, were benefitted, the former yielding ¼ more produce in weight, and the latter ⅓ more weight.

" *Barochan*, *26th October*, 1841. WM. FLEMING."

Note.—The prices paid by Mr. Fleming were as follow:—Bone dust (fine) 1s. 9d. per bushel; sulphate of ammonia (in crystals) 28s. per cwt.; potash (very impure) 24s. per cwt.; sulphate of soda (in crystals) 5s. per cwt.; nitrate of soda 22s.; and sal-ammoniac 60s. per cwt.

No. IV.

SUGGESTIONS FOR COMPARATIVE EXPERIMENTS WITH GUANO AND OTHER MANURES.

Guano is the name given in South America to the dung of the sea fowl which hover in countless flocks along the shores of the Pacific, and which, from time immemorial, have deposited their droppings on the rocks and the islands which are met with along the coast of Peru.

Besides the fresh white guano which is deposited year by year in these localities, there exist, in some spots, large accumulations more or less buried beneath a covering of drifted sand, which have been thus buried and partially preserved from an unknown antiquity. This ancient guano is of a brown colour, more or less dark, and forms layers or heaps of limited extent, but which are said sometimes to exceed even 60 feet in thickness.

In the time of the Incas this substance was known and highly valued as a manure,—the country along the coast for a length of 200 leagues was entirely manured by it,—the islands on which it was formed were carefully watched and preserved,—and it was declared to be a capital offence to kill any of the sea fowl by which it was deposited. Ever since that time it has been more or less employed for the same purpose, and much of the culture now practised on this thinly-peopled coast is entirely dependent for its success, if not for its existence, on the stores of manure which the sea fowl thus place within reach of those parts of the country which are susceptible of cultivation.

In modern times, however, the access of foreign shipping, and the want of careful protection, have driven away many of the sea fowl, and lessened to a very great degree the production of the recent guano. Thus the country is more dependent than in former times on the more ancient deposits, which are now assiduously sought for, and when discovered beneath the sand, are carefully excavated and transported to the sea-ports for sale.

The dung of birds of all kinds, when exposed to the air, gradually undergoes decomposition, gives off ammonia, and acquires a brown colour. As this ammonia is one of the most fertilizing substances it contains, it will be readily understood that the old brown guano is much less valuable as a manure than that which is recent and white; hence the care of the ancient Peruvians in collecting the fresh, and their comparative neglect of the ancient guano.

When the brown guano is put into water, a large quantity of it—sometimes 70 per cent. of the whole—is dissolved. Hence, it is, because the climate of Peru is so dry and arid that in the plains rain scarcely ever falls, that the guano can accumulate as it is found to do. North and south of this line of coast, where rains are less unfrequent, such accumulations are not met with, though the birds appear equally plentiful, and it may be safely stated that, had the climate of Peru been like that of England, the rains would have washed the guano from the rocks almost as rapidly as it was deposited.

Of the brown guano, several cargoes have lately been brought to England by an enterprising merchant in Liverpool, and it has been deservedly recommended to the attention of British agriculturists. It has already been tried upon various crops, both of hay and corn, upon turnips also, and upon hops, and there can be no doubt whatever that in our climate, as well as in that of Peru, it is fitted to promote vegetation to a very remarkable degree.

This brown guano varies much in quality, according probably to the degree of exposure to the air to which it has been subjected, or to its position in the deposit from which it has been dug. Two different portions, taken at random from the same box, gave me the following very different results:—

1°.—Water, salts and ammonia, and organic matter, expelled by a red heat,	23·5	per ct.
Sulphate of soda	1·8	"
Common salt, with a little phosphate of soda	30·3	"
Phosphate of lime, with a little phosphate of magnesia and carbonate of lime	44·4	"
	100*	

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* The first contained also 8 per cent. and the second 1½ per cent. of sand, which has been left out of the true composition of the guano considered as free from sand.

2°.—Ammonia	= 7·0	59·3 per ct.
Uric acid	= 0·8	
Water, carbonic and oxalic acids, &c, expelled by a red heat . .	= 51·5	
Common salt, with a little sulphate and phosphate of soda		11·4 "
Phosphate of lime, &c., ...		29·3 "
		100

According to M. Winterfeldt, this brown guano is sold at the ports near which it is obtained at about 3s. a cwt. It might, therefore, if this be correct, be imported into this country, and sold at less than 10s. per cent. The price at present asked, however, is 25s. per cent., a cost at which it is doubtful if the English agriculturist can afford to use it.

In any case it seems improbable that the guano can continue to be imported into this country for any length of time. It is absolutely necessary to the cultivation of the land in Peru,—and it is also diminishing in quantity,—the first settled government, therefore, which is formed in that country, must prohibit the further exportation of a substance so important to the national interests. It is a matter not unworthy of the attention of chemists, therefore, to consider whether a mixture similar to the guano and of equal efficacy, cannot be formed by art—not only at a cost so reasonable as at once to make the British farmer independent of the importer,—but also in such abundance as at the same time to place so valuable a manure within the reach of all.

The following mixture contains the several ingredients found in guano in nearly the average proportions; and I believe it is likely to be at least as efficacious as the natural guano, for all the crops to which the latter has hitherto been applied in this country :—

	£	s.	d.
315 lbs. (7 bushels) of bone dust at 2s. 9d. per bushel, .	0	19	0
100 lbs. of sulphate of ammonia,* containing 35 lbs. of ammonia at 20s. a cwt.	0	18	0
5 lbs. of pearl-ash	0	1	0
100 lbs. of common salt	0	2	0
11 lbs. of dry sulphate of soda, ...	0	1	0
531 lbs. of *artificial guano* cost	2	1	0

The quantity here indicated may be intimately mixed with 100 lbs. of chalk, and will be fully equal in efficacy, I believe, to 4 cwt. of guano, now selling at £5.

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* Sulphate of ammonia is now manufactured largely at Glasgow, and may be had for less than 20s. a cwt.

At the same time it is desirable that the relative efficacy b this mixture (artificial guano), and of the American guano, s be tried by actual experiment in comparison with other subst of known value, and which are supposed to act in a way som similar. The substances with which I would suggest that comparative experiments should, in the first place, be mad farm-yard manure, bone dust, and rape dust, and the foll scheme exhibits the proportions in which they may be added different plots of land on which the experiments are intended made:—

20 tons of farm-yard manure.	20 bushels of bones with ashes.	6 cwt. of guano, mixed with chalk or gypsum.	6 cwt. c artificial gu
10 tons do. with 10 bushels of bone dust.	20 cwt. of rape with ashes.	10 tons of farm-yard manure with 3 cwt. of guano.	10 tons farm-yard m with 3 cwt artificial gu
10 tons do. with 10 cwt. of rape dust.	10 cwt. of rape with 3 cwt. of guano.	10 tons do. with 2 cwt. of guano.	10 tons d with 2 cwt artificial gu

The practical farmer need not be deterred by the formi array of experiments above suggested. He may try any t three of them, and his results will be valuable in proportion t accuracy with which his land is measured and his manures crops weighed. I have taken 20 tons of farm-yard manure standard, though in many highly farmed parts of the count more than fifteen tons are usually applied. Twenty bushe bones are recommended by the Doncaster report, and I have l found that in the Lothians 1 cwt. of rape dust is considered t place 1 ton of farm-yard manure. This proportion of course vary with the quality of the latter manure; but whatever qua of this latter we take as the standard of comparison, it is ea adjust the proportions of the other substances accordingly. I not recommended any trial to be made with more than 6 cv guano, because, where farm-yard manure is valued only at 6 7s. per ton, 5 cwt. of the former would cost as much as 20 to the latter.*

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* When this paragraph was written, the price of guano was 25s. a c is now (May. 1842) reduced to 15s.

The above experiments are intended to be made with the green crop, and to be continued during an entire rotation:* any pair of them, however, may be tried on single crops, whether of corn or of turnips and potatoes. In this way guano ought also to be tried against nitrate of soda and against bones, upon seeds and upon old grass-lands. The mode in which such experiments may be made will speedily suggest themselves to the intelligent farmer. *In all cases the results should be accurately recorded, and, if possible, published.*

No. V.

OF THE EXAMINATION AND ANALYSIS OF SOILS.

1°. *Selection of specimens of soils.*—In the same field different varieties of soil often occur, and some recommend that in collecting a specimen for analysis, portions should be taken from different parts of the field and mixed together, by which an average quality of soil would be obtained. But this is bad advice, when the soils in different parts of the field are really unlike. Suppose one part of a field to be clay, and another sandy, as is often the case in this county, and that an average mixture of them is submitted to analysis, the result you get will apply neither to the one part of the field nor to the other—that is, it will be of little or no value. In selecting a specimen of soil, therefore, one or two pounds should be taken from each of four or five parts of the field where the soil appears nearly alike, these should be well-mixed together and dried in the open air or before the fire. Two separate pounds should then be taken from the whole for the purpose of analysis, or if it is to be sent to a distance should be tied up in clean strong paper, or what is much better, should be enclosed in clean well-corked bottles.

I.—OF THE PHYSICAL PROPERTIES OF THE SOIL.

2°. *Determination of the density of the soil.*—In order to determine the density of the soil, a portion of it must be dried at the temperature of boiling water (212°), till it ceases to lose weight, or upon a piece of white paper in an oven at a heat not great enough to render the paper brown. A common phial or other small bottle perfectly clean and dry may then be taken and filled up to a mark made with a file on the neck, with distilled or pure rain water, and then carefully weighed. Part of the water may then be poured out of the bottle, and 1000 grains of the dry soil introduced in its stead, the bottle must then be well shaken to allow the air to escape from the pores of the soil, filled up again with water to the mark on the neck, and again weighed. The weight of the soil divided by the difference between the weight of the bottle with soil and water, and the sum of the weights of the soil and the bottle of water together, gives the specific gravity.

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* By this I mean that the effect of these several manures, applied *once for all* to the green crop at the commencement of the rotation, should be traced on each successive crop through the entire course of cropping.

Thus, let the bottle with water weigh 2000 grains, and with water and soil 2600, then—

	Grains.
The weight of the bottle with water alone = ..	2000
The weight of the dry soil	1000
Sum, being the weight which the bottle with the soil and water *would have had* could the soil have been introduced without displacing any of the water	3000
But the weight of the bottle with soil and water was ..	2600
Difference, being the weight of water taken out to admit 1000 grains of dry soil	400

Therefore, 1000 grains of soil have the same *bulk* as 400 grains of water or the soil is 2½ times heavier than water, since $\frac{1000}{400}$ = 2·5 its specific gravity.

3°. *Determination of the absolute weight*—The absolute weight of a cubic foot of solid rock is obtained in pounds by multiplying its specific gravity by 63½—the weight in pounds of a cubic foot of water. But soils are porous, and contain more or less air in their interstices according as their particles are more or less fine, or as they contain more or less sand or vegetable matter. Fine sands are heaviest, clays next in order, and peaty soils the lightest. The simplest mode of determining their absolute weight, therefore, is to weigh an exact imperial half pint of the soil in any state of dryness, when this weight multiplied by 150, will give very nearly the weight of a cubic foot of the soil in that state.

4°. *Determination of the relative propositions of gravel, sand and clay.*—Five hundred grains of the dry soil may be boiled in a flask half full of water till the particles are thoroughly separated from each other. Being allowed to stand for a couple of minutes, the water with the fine matter floating in it may be poured off into another vessel. This may be repeated several times till it appears that nothing but sand or gravel remains. This sand and gravel is then to be washed completely out of the flask, dried, and weighed. Suppose the weight to be 300 grains, then 60 per cent.[*] of the soil is sand and gravel. The sand and gravel are now to be sifted through a gauze sieve more or less fine, when the gravel and coarse sand are separated, and may be weighed and their proportions estimated.

These separate portions of gravel and sand should now be moistened with water and examined carefully with the aid of a microscope, with the view of ascertaining if they are wholly silicious, or if they contain also fragments of different kinds of rock, sand-stones, slates, granites, traps, lime-stones or iron-stones. A few drops of strong muriatic acid (spirit of salt) should also be added—when the presence of lime-stone is shown more distinctly by an effervescence, which can be readily perceived by the aid of the glass,—of per-oxide of iron by the brown colour which the acid speedily assumes,—and of black oxide of manganese by a distinct smell of chlorine which is easily recognized. In the subsequent description of the soil, these points should be carefully noted.

Suppose the sand and gravel to contain half its weight of fine sand, then our soil would consist of coarse sand and small stones 30 per cent., fine sand 30 per cent., clay and other lighter matters 40 per cent.

5°. *Absorbing power of the soil.*—A thousand grains of the perfectly *dry* soil, crushed to powder, should be spread over a sheet of paper and exposed to the air for twelve or twenty-four hours, and then weighed. The increase of weight shows its power of absorbing moisture from the air. If it amount to 15 or 20 grains, it is so far an indication of great agricultural capabilities.

6°. *Its power of holding water.*—This same portion of soil may now be put into a funnel upon a *double*[†] filter and cold water poured upon it, drop by drop, till the whole is wet and the water begins to trickle down the neck of the filter. It may now be covered with a piece of glass and allowed to stand for a few hours occasionally adding a few drops of water, until there remains n doubt of the whole soil being perfectly soaked. The two filter and the soil are then to be removed from the funnel, the filter opened and spread for a few minutes upon a linen cloth to remove the drops of water which adhere to the paper. The we soil and inner filter being now put into one scale, and the oute filter in the other, and the whole carefully balanced, the true weight of the wet soil is obtained. Suppose the original thousand grains now to weigh 1400, then the soil is capable of holding 40 per cent. of water.*

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[*] As 500 : 300 :: 100 to 60 per cent.

[†] That is, one filter within another.

7°. *Rapidity with which the soil dries.*—The wet soil with its filter may now be spread out upon a plate and exposed to the air, in what may be considered ordinary circumstances of temperature and moisture, for 4, 12, or 24 hours, and the loss of weight then ascertained. This will indicate the comparative rapidity with which such a soil would dry, and the consequent urgent demand for draining, or the contrary. As great a proportion of the water is said to evaporate from a given weight of sand saturated with water, in 4 hours, as from an equal weight of pure clay in 11, and of peat in 17 hours—when placed in the same circumstances.

8°. *Power of absorbing heat from the sun.*—In the preceding experiment a portion of pure quartz sand or of pipe clay may be employed for the purpose of obtaining a *comparative* result as to the rapidity of drying. The same method may be adopted in regard to the power of the soil to become warm under the influence of the sun's rays. Two small wooden boxes, containing each a layer of one of the kinds of soil, two inches in depth, may be exposed to the same sunshine for the same length of time, and the heat they severally acquire determined by a thermometer, buried about a quarter of an inch beneath the surface. Soils are not found to differ so much in the actual temperature they are capable of attaining under such circumstances—most soils becoming 20° or 30° warmer than the surrounding air in the time of summer—as in the relative *degree of rapidity* with which they acquire this maximum temperature—and this, as stated in the text, appears to depend chiefly upon the darkness of their colour. The determination of this quality, therefore, except as a matter of curiosity, may, at the option of the experimenter, be dispensed with.

II.—OF THE ORGANIC MATTER PRESENT IN THE SOIL.

9°. *Determination of the per centage of organic matter.*—The soil must be thoroughly dried in an oven or otherwise, at a temperature not higher than between 250° to 300° F. Humic and ulmic acids will bear this latter temperature without change. An accurately weighed portion (100 to 200 grains) must then be burned in the open air, till all the blackness disappears. This is best done in a small platinum capsule over an argand spirit or gas lamp. The loss indicates the total weight of organic matter present. It is scarcely ever possible, however, to render soil absolutely *dry* without raising them to a temperature so high as to char the organic matter present, and hence its weight, as above determined, will always somewhat *exceed* the truth, the remaining water being driven off along with the organic matter when the soil is heated to redness. This excess, also, will in general be greater in proportion to the quantity of clay in the soil, since this is the ingredient of most soils from which the water is expelled with the greatest difficulty.

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* 1000 : 400, the increase of weight as 100 : 40.

10°. *Determination of the humic acid.*—This acid, whether merely mixed with the soil, or combined with some of the lime and alumina it contains, is extracted by boiling with a solution of the common soda of the shops. Into about two ounces by measure of a saturated solution of this salt, contained in a flask, 200 or 300 grains of soil, previously reduced to coarse powder, are introduced, an equal bulk of water added, and the whole boiled or digested on the sand bath with occasional shaking for an hour. The flask is then removed from the fire, filled up with water, well shaken, and the particles of soil afterwards allowed to subside. The clear liquid is then poured off. If it has a brown colour it has taken up some humic acid. In this case, the process must be repeated once or twice with fresh portions of the soda solution, till the whole of the soluble organic matter appears by the pale colour of the solution to be taken up. These coloured solutions are then to be mixed and filtered. This filtering generally occupies considerable time, the humic and ulmic acids clogging up the pores of the filter in a remarkable manner, and permitting the liquid to pass through sometimes with extreme slowness.

When filtered, muriatic acid is to be slowly added to the coloured liquid—which should be kept in motion by a glass rod—till effervescence ceases, and the whole has become distinctly sour. On being set aside the humic acid falls in brown flocks. A filter is now to be dried and carefully weighed,* the liquid filtered through it, and the humic acid thus collected. It must be washed in the filter with pure water—rendered slightly sour by muriatic acid†—

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* This is best effected by putting the filter into a covered porcelain crucible of known weight, and heating it for ten minutes over a lamp or otherwise, at a temperature which just does not discolour the paper, allowing then the crucible to cool under cover, and when cold weighing it. The increase above the known weight of the crucible is that of the filter, which, besides being recorded in the experiment book, should also be marked in several places on the edge of the filter with a black lead pencil.

† This is to prevent in some measure the humic acid from passing through

till all the soda is separated from it,* when it is to be dried at 250° F., till it ceases to lose weight. The final weight, minus that of the filter, gives the quantity of humic acid contained in the portion of soil submitted to examination. As it is rarely possible to wash the humic acid perfectly upon the filter, rigorous accuracy requires that the filter and acid should be burned after being weighed, and the weight of ash left, minus the known weight of ash left by the filter,† deducted from that of the acid as previously determined. It is to be observed here that by this, which is really the only available method we possess of estimating the humic acid, a certain amount of loss arises from its not being wholly insoluble, the acid liquid which passes through the filter being always more or less of a brown colour.‡

11°. *Determination of the insoluble humus.*—Many soils after this treatment with carbonate of soda are still more or less of a brown colour, evidently due to the presence of other organic matter. To separate this, Sprengel recommends to boil the soil, which has been treated with carbonate of soda, and which we suppose still to remain in the flask, with a solution of caustic potash, repeated, if necessary, as in the case of the soda solution. By this boiling, the vegetable matter, which was insoluble in the carbonate of soda, is changed in constitution and dissolves in the caustic potash, giving a brown solution, from which it may be separated in brown flocks by the addition of muriatic acid, and then collected and weighed as above described.

In some soils, also, distinct portions of vegetable fibre, such as portions of roots, &c., are present, and may be separated, mechanically dried, and weighed.

12°. *Of other organic substances present in the soil.*—The sum of the weights of the above substances deducted from the whole

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the filter, which it is very apt to do, when the saline matter is nearly washed out of it.

[*] This is ascertained by collecting a few drops of what is passing through upon a piece of clean glass or platinum, and drying them over the lamp, when, if a perceptible stain or spot is left, the substance is not sufficiently washed.

[†] The ash left by the paper employed for filters should always be known. This is ascertained, once for all, by drying a quantity of it in the way described in the previous note, weighing it in this dry state, burning it, and again weighing the ash that is left. In good filtering paper, the ash ou not to exceed one per cent.

[‡] The portion which thus remains in solution may be precipitate ding a small quantity of a solution of alum, and afterwards pouring nia in excess. The alumina falls coloured by the organic matt being collected on a filter, washed, and dried, the weight of in the precipitate may be determined approximately as de- (2°).

weight of organic matter, as determined by burning, gives that of *other* organic substances present in the soil. The quantity of these is in general comparatively small, and, unless they are soluble in water, there is no easy method of separating them, and determining their weight. The following two methods, however, may be resorted to:—

1°. Half a pound or more of the moist soil may be boiled with two separate pints of distilled water, the liquid filtered and evaporated to a small bulk. From clay soils, when thus boiled with water, the fine particles do not readily subside. Sometimes, after standing for several days, the water is still muddy, and passes muddy through the filter, but, after being evaporated, as above recommended, to a small bulk, most of the fine clayey matter remains on the paper when it is again filtered. As soon as it has thus passed through clear, the liquid may be evaporated to perfect dryness at 250° F., and weighed. Being now treated with water—a portion will be dissolved—this must be poured off, and the insoluble remainder again perfectly dried and weighed. If this remainder be now heated to redness in the air, any organic matter it contains will be burned off, and its weight ascertained by the loss on again weighing. This loss may be considered as humic acid rendered insoluble by drying.* It does not require to be added to the weight of humic acid already determined (10°), because in that experiment a portion of soil was employed which had *not been boiled in water*, and from which therefore the carbonate of soda would at once extract *all* the humic acid. The present experiment need only be made when it is desirable to ascertain how much humic acid a soil contains in a state in which it is soluble *in* water. Where ammonia, potash, or soda is present in the soil, some chemists consider this quantity to be very considerable, and to exercise an important influence upon vegetation.

That which was taken up by water from the dried residuum is again to be evaporated to dryness, dried at 150°, weighed, and burned at a *low* red heat. The loss is organic matter, and may have been crenic or apocrenic, or some other of the organic acids formed in soils, the compounds of which, with lime, alumina, and protoxide of iron, are soluble in water. If any little sparkling or burning like match-paper be observed during this heating to redness, it may be considered as an indication of the presence of nitric acid —in the form of nitrate of potash, soda, or lime. In this case the loss by burning will slightly exceed the true amount of organic matter present, owing to the decomposition and escape of the nitric acid also. The mode of estimating the quantity of this acid, when it is present in any sensible proportion, will be hereafter described

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* See Lecture xiii., p. 409.

2°. The caustic potash employed to dissolve the insoluble humus (11°) takes up also any alumina which may have been in combination with the humic acid, or may still remain united to the mudesous* or other organic acids. When the solution is filtered and the humic acid separated by the addition of muriatic acid till the liquid has a distinctly sour taste, this alumina, and the acids with which it is in combination, still remain in solution. After the brown flocks of humic acid, however, are collected on the filter, the alumina may be thrown down from the filtered solution by adding caustic ammonia to the sour liquid, until it has a distinctly ammoniacal smell. The light precipitate which falls must be collected on a filter and washed with hot water till the potash is as completely separated as possible. It is then to be dried at 300° F., weighed and heated for some time in a close crucible over the lamp, at a temperature which *begins* to discolour it and again weighed. Being now burned in the air till it is quite white, and weighed, the last loss may be considered as mudesous or some similar acid.

The reason why this second method of drying over the lamp is here recommended, is, that alumina and nearly all its compounds part with their water with great difficulty, and even with the precautions above indicated, it is not unlikely that a larger per centage of organic matter may thus be indicated, than in reality exists in the soil. The check which the accurate experimenter has upon all these determinations is this, that the sum of the several weights of the humic acid, the insoluble humus, the vegetable fibre, and of the crenic and mudesous acids, if present, should be somewhat less than that of the whole combustible organic matter, as determined by burning the dry soil in the open air (9°). This quantity we have seen to be in most cases greater than the truth, because any remaining water or any nitric acid the soil may contain, are at the same time driven off.

I may further remark upon this subject that the quantity of alumina thus dissolved by the caustic potash is in most soils very small, and the quantity of organic matter by which it is accompanied in many cases so minute, that the determination of it may be considered as a matter of curiosity, rather than one of practical importance.

III.—OF THE SOLUBLE SALINE MATTER IN THE SOIL.

13°. With a view to determine the *nature* of the soluble saline matter in the soil, a preliminary experiment must be made. An unweighed portion must be introduced into five or six ounces of boiling distilled water in a flask, and kept at a boiling temperature, with occasional shaking for a quarter of an hour. It may then b allowed to subside, after which the liquid is to be filtered till it passes through clear. It is then to be tested in the following manner. Small separate portions are to be put into so many clean wine glasses, and the effect produced upon these by different chemical substances carefully noted. If with a few drops of

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* Except where gypsum is present in the insoluble portion, which unfrequently the case, when the loss will be partly water—since

a. *Nitrate of Baryta*, it gives a white powdery precipitate, which does not disappear on the addition of nitric or muriatic acid, *the solution contains sulphuric acid*. If the precipitate does disappear, it contains *carbonic acid*. In this latter case, the liquid will also effervesce on the addition of either of the acids above mentioned.

b. If with *oxalate of ammonia*, it gives either immediately, or after a time, a white cloud, it contains lime,* and the greater the milkiness, the larger the quantity of lime may be presumed to be.

c. If with *nitrate of silver* it gives a white curdy precipitate, insoluble in pure nitric acid, and speedily becoming purple in the sun, it may be presumed to contain chlorine.

d. If with *caustic ammonia* it gives a pure white gelatinous precipitate, it contains either *alumina, or magnesia, or both*. In this case, muriatic acid must be added till the precipitate disappears, and the solution is distinctly acid. If on the addition of ammonia in excess, the precipitate reappears undiminished in quantity, it contains *alumina only*. If it be distinctly *less* in quantity, we may infer the presence of both magnesia and alumina; and if no precipitate now appears that it contains *magnesia only*. If a large quantity of magnesia be present, it may be necessary to re-dissolve and acidify the solution a second time before,—on the *re*-addition of ammonia, the precipitate would entirely disappear.

If the precipitate, by ammonia, have more or less of a brown colour, the presence of *iron*, and perhaps *manganese*, may be inferred. If, on the second addition of ammonia, the colour of the precipitate has disappeared, it has been due to manganese only—if it still continue brown, it is owing chiefly or altogether to the presence of oxide of iron. If the colour of the precipitate, by ammonia, be very dark, it consists almost entirely of oxide of iron, and may contain little or no alumina,—when it is also more or less brown, the presence of both alumina and oxide of iron may certainly be inferred.

e. If, after the first addition of ammonia, the solution be filtered to separate the alumina, the oxides of iron and manganese,

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after being dried at 250°, loses still about 20·8 per cent. of water when heated to redness.

* The learned reader will understand why, for the sake of simplicity, I take no notice of substances not likely to be present in the soil—as, for example, baryta, which would here be thrown down along with the lime, or of oxalic acid which equally with the sulphuric or carbonic (*a*), would give a white precipitate with nitrate of baryta.

and the magnesia that may be thrown down—if oxalate of ammonia be then added till all the lime falls, and the liquid be again filtered, evaporated to dryness, and then heated to incipient redness in the air, till the excess of oxalate of ammonia is destroyed and driven off—and if a soluble residue then remain,* it is probable that *potash* or *soda*, or both, are present. If, on dissolving this residue in a little water, the addition of a few drops of a solution of tartaric acid to it produce a deposit of small colourless crystals (of cream of tartar,) or if a drop of a solution of bi-chloride of platinum produce in a short time a yellow powdery precipitate, it contains *potash*. If no precipitate is produced by either of these—re-agents as they are called—the presence of soda may be inferred. If the yellow precipitate, containing potash and platinum, be separated by a filter, and the solution after being treated with sulphuretted hydrogen and filtered to separate the excess of bi-chloride of platinum, be evaporated to dryness—if, then, a soluble saline residue still remain, the solution contains *soda* as well as potash.

It is to be observed, that some magnesia, if present, may accompany the potash and soda through these several processes. After the separation of the potash, a little caustic ammonia will detect the presence of magnesia, but it will rarely be found so far to interfere with this preliminary examination as to prevent the experimenter from arriving at correct results. (See p. 55, *f*.)

f. If the addition of bi-chloride of platinum to the solution directly filtered from the soil give a yellow precipitate, it contains either *potash* or *ammonia*. If, when collected on the filter, dried, and heated to bright redness in the air, white fumes are given off by this yellow precipitate, and only a spongy mass of metallic platinum remains behind, the solution contains *ammonia* only. If, with the platinum, be mixed a portion of a soluble substance having a taste like that of common salt, and giving again a yellow precipitate with bi-chloride of platinum, it contains *potash*—and if the spongy platinum contained in the burned mass, after prolonged heating, amount to more than 57 per cent. of its weight, or if it be to the soluble matter in a higher proportion than that of 4 to 3, the solution contains both *potash* and *ammonia*.

The presence of *ammonia* in the saline substance, or in the concentrated solution, is more readily detected by adding a few drops of a solution of caustic potash, when the smell of ammonia becomes perceptible, or if in too small quantity to be detected by the smell, it will, if present, restore the blue colour to reddened litmus paper. This experiment is best made in a small tube.

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* Not precipitated from its solution by ammonia, for if precipitated it is partly at least chloride of magnesium.

g. If, when the solution, obtained directly from the soil, is evaporated to dryness, and the residue heated to redness in the air, a deflagration or burning like match-paper be observed, nitric acid is present. Or, if the dry mass, when put into a test tube with a little muriatic acid, evolves distinct red fumes on being heated, or enables the muriatic acid to dissolve gold-dust, and form a yellow solution; or, if to a colourless solution of green vitriol (sulphate of iron), introduced into the tube along with the muriatic acid, it imparts more or less of a brown colour—in any of these cases the presence of nitric acid may with certainty be inferred. It will be only on rare occasions, however, that salts, so soluble as the nitrates, will be found in sensible quantity in the small portion of a soil likely to be employed in these preliminary experiments.

h. If ammonia throw down nothing (see under *d*) from the solution, and if no precipitate appear when the chloride of calcium or magnesium is afterwards added, the solution contains no *phosphoric acid*. But if ammonia cause a precipitate, and after this is separated by the filter, nothing further falls on adding either of the above chlorides, the phosphoric acid, if any is present, will be contained in the precipitate which is upon the filter. Let this, after being well washed with distilled water, be dissolved off with a little pure nitric acid diluted with water, and then neutralized as exactly as possible with ammonia. If a solution of acetate (sugar) of lead now throw down a white precipitate, phosphoric acid is present. The phosphate of lead—the white precipitate which falls—melts readily before the blowpipe, and, on cooling, crystallizes into a bead with beautiful crystalline facets.

Or, if the precipitate thrown down by ammonia be wholly or in part insoluble in pure acetic acid (vinegar), that which is undissolved contains phosphoric acid. If acetic acid dissolve the whole, it may be inferred that no phosphoric acid is present in the soil.

But if no precipitate be thrown down by ammonia, instead of the chloride of calcium above recommended a few drops of a dilute solution of alum may be mixed with the solution, after adding the ammonia, and the whole well shaken. If the white precipitate, which now falls, dissolve wholly in acetic acid, no phosphoric acid is present, and *vice versa*.

These preliminary trials being made, notes should be kept of all the appearances presented, as the method to be adopted for separating and determining the weight of each substance will depend upon the number and nature of those which are actually found to be present.

14°. *Determination of the quantities of the several constituents of* *the soluble saline matter.*—The quantity of soluble saline matter extracted from a moderate quantity of any of our soils is rarely so great as to admit of a rigorous analysis, and the preceding determination of the *kind* of substances it contains will be in most cases sufficient. Cases may occur, however, in which much saline matter may be obtained;* it will be proper, therefore, briefly

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* This is the case with the rich soils of India and Egypt, and of other warm climates. This will appear from the following analyses of some Indian soils, made on the spot by Mr. Fleming, of Barochan, during the hours of leisure left him by his more important duties:—

Analysis of Soils in North and South Behar, Bengal Presidency—(200 *grains of each being analysed.*)

Water of Absorption.	Matter destructible by heat.	Carbonate of Lime.	Carbonate of Magnesia.	Oxide of Iron.	Alumina or Clay.	Silicious Sand.	Soluble Matter, (Chlorides, Sulphates, Nitrates.)	Loss of Weight.	REMARKS.
22	4	15	7	12	9	126	2	9	1°. Near Gya, South Behar.—Of a dark colour, soapy to the touch when moist, hard and cracks when dry; yields a crop of rice and one of wheat every year. Never lies fallow, but is covered with water during part of the rainy season, and is productive—from 30 to 50 bushels of wheat per acre.
20	14	10	8	13	14	115	1	5	2°. Soil from the same district.—Also soapy when moist and cracks when dry—rather more productive than No. 1.
20	6	11	4	20	20	114	3	6	3°. From the same district.—Heavy red clay soil, producing wheat, peas, cotton or poppy in the dry season, and Indian corn and millet in the wet season; not inundated in the rains, and sometimes manured with ashes of wood and cow dung.
19	9	9	1	2	16	130	7	7	4°. Soil from North Behar, Tirhoot.—A deep loam, yielding two crops yearly; not inundated, producing wheat, barley, Indian corn, indigo, poppy, &c. From 25 to 35 bushels of wheat per acre; is not usually manured.
18	7	8	2	1	12	140	6	6	5°. Tirhoot.—Soil light coloured; producing nearly the same crops, but not so productive as No. 4. Saline efflorescence in patches.
12	3	4	-	1	5	152	14	9	6°. Tirhoot.—Not so productive as No. 5, and some patches nearly sterile from the saline efflorescence, except in the rainy season, when it produces good crops of Indian corn. Soil light coloured.

I have already alluded (Lec. VIII., p. 239) to the influence which this large proportion of saline matter exercises upon the luxuriance of the vegetation.

to state the methods by which the respective quantities of each contituent may be accurately determined.

a. Estimation of the Sulphuric Acid.—The solution being gently warmed, a few drops of nitric acid are to be added until the solution is slightly acid, and any carbonic acid that may be present is expelled, after which nitrate of baryta is to be added to the solution as long as any thing falls. The white precipitate (sulphate of baryta) is then to be collected on a weighed filter, well washed with distilled water, dried over boiling water as long as it loses weight, and then weighed. The weight of the filter being deducted,* every 100 grains of the dry powder are equal to 34·37 grains of sulphuric acid.

b. Estimation of the Chlorine.—The solution of nitrate of silver must be added as long as any precipitate falls, the precipitate then washed, dried at 212° F., and weighed as before. Every 100 grs. of chloride of silver indicate 24·67 grs. of chlorine, or 40·88 grs. of common salt.

c. Estimation of the Lime.—A little diluted muriatic acid being added to throw down the excess of silver, and a little sulphuric acid to separate the excess of baryta, added in the former operations, and the precipitates separated by filtration—caustic ammonia is to be poured in, till the solution is distinctly alkaline. If no precipitate fall, oxalate of ammonia is to be added as long as any white powder appears to be produced. The solution must then be left to stand over night—that the whole of the lime may separate,—the white powder afterwards collected on a filter, washed, dried, and burned with the filter, at a low red heat. The gray powder obtained is carbonate of lime, every 100 grs. of which contain 43·71 grs. of lime.

d. Estimation of the Oxide of Iron and of the Alumina.—But if a precipitate fall on the addition of ammonia, as above prescribed—the solution may contain magnesia, alumina, and the oxides of iron, and manganese. In this case the precipitate is to be re-dissolved by the addition of muriatic acid, till it is distinctly acid, and ammonia again added in slight excess. If any precipitate now fall, it will consist only of alumina and oxide of iron, unless magnesia and oxide of manganese be present in large proportion, when a minute quantity of each may fall at the same time.

The precipitate is to be collected on the filter as quickly as possible,—the funnel being at the same time covered with a plate of glass to prevent as much as possible the access of the air,—washed with distilled water, and then re-dissolved in muriatic acid. This is best effected by spreading out the filter in a small porcelain dish, adding dilute acid till all is dissolved, and then washing the paper well with distilled water. A few drops of nitric acid are then to be added, and the solution heated, to peroxidize the iron. A solution of caustic potash added *in excess* will at first throw down both the oxide of iron and alumina, but will afterwards re-dissolve the alumina, and leave only the oxide of iron. This is to be collected on a filter, washed, dried, heated to redness, and weighed. Every 100 grains of this peroxide of iron are equal to 89·78 grains of protoxide, in which state it had most probably existed in the original solution.

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* Or the whole may be heated to redness in the air, and the filter burned away. In this case the weight of ash left by the paper must be ascertained by previous trials, and the due proportion deducted from the weight of the sulphate.

To the potash solution muriatic acid is added till the alkali is saturated, or till the solution reddens *litmus paper*,* when the addition of ammonia precipitates the alumina. As it is difficult to wash this precipitate perfectly free from potash, it is better to dissolve it again in muriatic acid, and to re-precipitate it by caustic ammonia. When well washed, dried, and weighed, this precipitate gives the true quantity of alumina present in the portion of salt submitted to analysis.

e. *Estimation of the Manganese.*—To the ammoniacal solutions from which the oxalate of lime has been precipitated (*c*), a solution of hydro-sulphuret of ammonia is to be added. The manganese will fall in the form of a flesh red sulphuret. When this precipitate has fully subsided, it must be collected on the filter and washed with water containing a very little hydro-sulphuret of ammonia The filter is then put into a glass or porcelain basin, the precipitate dissolved off by dilute muriatic acid, and the solution filtered, if necessary. A solution of carbonate of potash then throws down carbonate of manganese, which is collected, dried, and heated to redness in the air. Of the brown powder obtained 100 grains indicate the presence of 93·84 grains of protoxide of manganese in the salt or solution under examination.

f. *Estimation of the Magnesia.*—If no potash or soda be present in the residual solution, the determination of the magnesia is easy. A few drops of muriatic acid are added, and the whole gently heated, and afterwards filtered, to separate the sulphur of the excess of hydro-sulphuret of ammonia previously added.

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* Litmus paper is paper stained by dipping it into a solution of litmus, a vegetable blue color, prepared and sold for the purpose of detecting the presence of *free* acids, by which it is reddened.

The solution is then evaporated to dryness, and the dry mass heated to redness to drive off all the ammoniacal salts previously added. A few drops of diluted sulphuric acid are added to what remains, to change the whole of the magnesia into sulphate, the mass again heated to redness and weighed. One hundred grains of this sulphate indicate the presence of 34·01 grs. of pure magnesia.

But if potash or soda be present—the weight of which it is desirable to determine—the simplest method is to take a fresh portion, 15 to 20 grains, of the saline matter under examination. If any sulphuric acid be present in it add nitrate of baryta drop by drop to the solution till the whole of the acid is exactly thrown down—if possible, no excess of baryta being left in the solution—then precipitate the alumina and oxides of iron and manganese, and the lime, if any of these be present, and, finally evaporate to dryness, and heat to redness as before. The dry mass is now to be dissolved in water, adding, *if necessary to complete the solution*, a few drops of muriatic acid. A quantity of red oxide of mercury is then to be added to the concentrated solution, and the whole boiled down to dryness. Water now dissolves out the potash and soda only, and leaves the magnesia mixed with oxide of mercury. This is to be collected on a filter, washed—not with too much water—and heated to redness, when the magnesia remains pure, and may be weighed.

g. *Estimation of the Potash and Soda.*—The solution containing the potash and soda, is to be evaporated to dryness, and heated to redness to drive off any mercury it may contain. The weight of the mass which consists of a mixture of chloride of potassium with chloride of sodium (common salt) is accurately determined, it is then dissolved in a small quantity of water, and a solution of bi-chloride of platinum added to it in sufficient quantity. Being evaporated by a very gentle heat nearly to dryness, weak alcohol is added which dissolves the chloride of sodium and any excess of salt of platinum which may be present. The yellow powder is collected on a weighed filter, washed well with spirits, dried by a gentle heat and weighed on the filter. Every 100 grains indicate the presence of 19·33 grains of potash, or 30·56 grains of chloride of potassium.

The quantity of chloride of sodium is estimated from the loss. The weight of the chloride of potassium above found, is deducted from that of the mixed chlorides previously ascertained, the remainder is the weight of the chloride of sodium. Every 100 grains of chloride of sodium (common salt) are equivalent to 53·29 of soda.

h. *Estimation of the Ammonia.*—If ammonia be present in the solution along with potash and other substances, the method by which it can be most easily estimated is to introduce the solution into a large tubulated retort, to add water until the solution amounts to nearly an English pint—then to introduce a quantity of caustic potash or caustic baryta, and to distil by a gentle heat into a close receiver, containing a little dilute muriatic acid, until fully one-half has passed over. Bi-chloride of platinum is then to be added to the solution, which has come over, previously rendered slightly acid by muriatic acid, and the whole is evaporated *nearly* to dryness by a very gentle heat. Dilute alcohol is then added to wash out the excess of the salt of platinum, and the yellow powder is collected on a filter, washed with spirit, dried by a *very* gentle heat, and weighed. One hundred grains indicate the presence of 7·69 grains of ammonia.

Or the yellow powder, without being so carefully dried, may be heated to redness, when only metallic platinum will remain. One hundred grains of this metallic platinum indicate the presence of 17·39 grains of ammonia.

i. Estimation of the Phosphoric Acid.—If phosphoric acid be present in the solution, it will be contained in the precipitate thrown down by ammonia (*d*). As it will never be found but in very small quantity, the rigorous determination of its amount is a matter of considerable difficulty. The following method already described (13°, *h*), may be adopted. The precipitated alumina, oxide of iron, &c., thrown down by ammonia, after being dried, are to be mixed with three times their weight of pure dry carbonate of soda, and fused together in a platinum crucible. The fused mass is then to be treated with cold distilled water till every thing soluble is taken up. The filtered solution is next to be gently heated and exactly neutralized with nitric acid, when a solution of nitrate of silver will throw down a *white* precipitate of phosphate of silver, which is to be collected, dried, and weighed. Every hundred grains of it are equal to 23·51 of phosphoric acid, or 48·50 of bone earth.

Or the filtered solution may be treated with muriatic acid, ammonia added in excess, and then a solution of chloride of calcium. *Bone earth* will fall, which is to be collected, washed, heated to redness, and weighed. One hundred grains of it contain 48·45 of phosphoric acid. The former method is probably the better, but neither of them will give more than an approximation to the truth.

That portion of the fused mass which cold water has refused to take up is to be dissolved in muriatic acid, and again precipitated by ammonia. The clear solution which passes through is to be added to the first ammoniacal solution (*c*), from which the lime is not yet thrown down, as when little alumina and oxide of iron are present, a small portion of lime and magnesia, if contained in the salt under examination, may have fallen along with them in combination with phosphoric acid.

The alumina and oxide of iron which rest on the filter are to be separated and estimated as already described (*d*).

k. *Estimation of the Carbonic Acid.*—The lime and magnesia dissolved by cold diluted muriatic acid are partly in combination with carbonic acid and partly with the humic, ulmic, and other vegetable acids. To determine the carbonic acid, 100 grains of the soil dried at 212°, are to be introduced into a small weighed flask, and then just covered by a weighed quantity of cold diluted muriatic acid. After 12 hours, when the action has ceased, a small tube is to be introduced into the flask and air sucked through it till the whole of the carbonic acid is drawn out of the flask. The loss of weight will indicate the amount of carbonic acid very nearly. It would be more rigorously ascertained by fitting into the mouth of the flask a tube containing chloride of calcium, and then heating the solution to expel the carbonic acid.

Every hundred grains of carbonic acid indicate the presence of 77·24 grains of lime in the state of carbonate. The weight of lime in this state, deducted from the whole weight obtained as above (*c*), gives the quantity which is in combination with other *organic* acids.

IV.—OF THE INSOLUBLE EARTHY MATTER OF THE SOIL.

15°. When the soil has been washed with distilled water as above directed—it is to be treated in the cold with diluted muriatic acid—and allowed to stand with occasional stirring for 12 hours. By this means the carbonates of lime, magnesia, and iron, and the phosphates of lime, and alumina are dissolved—with any lime, magnesia, oxide of iron, or alumina, which may have been in combination with organic acids. The iron, alumina, and phosphoric acid are to be precipitated by ammonia, the lime by oxalate of ammonia, and such other steps taken as may be necessary, according to the methods already described.

16°. The undissolved portion may now be treated with hot concentrated muriatic, kept warm and occasionally stirred for two or three hours, and the solution afterwards evaporated to dryness. The dry matter is then to be moistened with a few drops of muriatic acid, and subsequently treated with water. What remains undissolved is silica, which must be collected on a filter, dried, heated to redness, and weighed.

The solution may contain oxide of iron, alumina, lime, magnesia, potash, and soda. Any of the four last substances, which m detected in it, have most probably existed in the soil, in com tion with silica—in the state of silicates.

17°. But the soil may still contain alumina, not soluble in muriatic acid. To ascertain if this be the case, and to separ and determine this portion of the alumina, if present, either of t methods may be adopted.

a. The residual soil may be drenched with concentrated sulphu ric acid and heated for a considerable time till the sulphuric acid is nearly all driven off. On treating with water, and adding ammonia to the filtered solution, alumina, and oxide of iron, if any have been present, will be thrown down. If any alumina be thus separated, the treatment with sulphuric acid must be repeated, till on treating with water and ammonia, as before, no more alumina appears.

b. Or that portion of the soil on which hot muriatic acid refuses to act may be mixed with twice its weight of carbonate of soda, and heated in a platinum crucible till the whole is completely fused. The mass is then to be treated with diluted muriatic acid till every thing soluble is taken up, the filtered solution evaporated to dryness, the dry mass moistened with muriatic acid, and again treated with water. If any thing is left undissolved it will be silica, and if any alumina be contained in the solution, it will be precipitated by ammonia, and may be collected, washed, dried, and weighed, as already described. The solution may also be tested for magnesia, and if any be present it may be separated by the process already explained.

The former of these two methods is to be preferred as the simpler, though it will also require considerable care and attention. 'That which the sulphuric acid leaves behind must be washed, dried, heated to redness, and weighed. It will be found to consist chiefly of quartz sand, and finely divided silicious matter.'

The accuracy and care with which the whole of these processes have been conducted is tested by adding together the weights of the several substances that have been separately obtained. If this sum does not differ more than one per cent. from the weight of the soil employed, the results may be considered as deserving of confidence. One of the points in which a beginner is most likely to err is in the washing of the several precipitates he collects upon his filters. As this is a tedious operation, he is very likely to wash them, at first, only imperfectly, and thus to have an excess of weight when his quantities are added together—whereas a small loss is almost unavoidable. The precipitates should always be washed with distilled water, and the washing continued till a drop of what passes through leaves no stain when dried upon a bit of glass.

The following scheme exhibits the successive steps which are to be taken in order to separate the several inorganic substances from the solution in muriatic acid by the methods above described.

Digest the soil in distilled water, dried at 230°, weigh, digest with dilute muriatic acid for 12 hours, and filter the solution. This solution should be *decidedly sour*, and may contain lime, magnesia, alumina, oxide of iron, oxide of manganese, potash, soda, and phosphoric acid.

1 Add caustic ammonia in excess

9 To the clear solution add oxalate of ammonia, and cover it from the air.

11 Add hydrosulphuret of ammonia.

13 Render sour by muriatic acid, boil, filter, evaporate to dryness, and heat to incipient redness to drive off all the ammoniacal salts. Re-dissolve in a little water, mix with a little pure red oxide of mercury, evaporate again to dryness, heat to redness, and treat with water.

12 If manganese is present it falls as sulphuret; dissolve in muriatic acid, precipitate by carbonate of soda, wash, heat to redness in the air, and weigh, p. 55.

15 The solution contains the chlorides of potassium and sodium, if present. Evaporate to dryness, weigh, re-dissolve in water, and add bi-chloride of platinum to separate the potash, p. 56.

14 Caustic magnesia remains; wash, heat to redness, and weigh.

17 The chloride of sodium remains in solution, and its weight is found by deducting from the weight of the mixed chlorides (15) that of the chloride of potassium (16).

16 Wash the precitate with weak alcohol, dry by a gentle heat and weigh.

10 Oxalate of lime falls, wash, heat to redness to convert it into *carbonate*, and weigh.

2 Oxide of iron, alumina, and phosphoric acid are precipitated. Digest in acetic acid.

6 Solution contains alumina and oxide of iron; add ammonia, and digest the precipitate in a solution of caustic potash, p. 54.

8 Add muriatic acid till the solution is sour; then ammonia in excess. Alumina falls; wash and weigh.

7 Oxide of iron remains; wash & weigh.

3 Phosphates of alumina and iron remain undissolved. Fuse with carbonate of soda, and wash with distilled water, p. 56.

5 Phosphoric acid is dissolved. Neutralize by nitric acid, & add nitrate of silver, when phosphate of silver will fall; or by muriatic acid, and add chloride of calcium and caustic ammonia, when bone - earth will fall, p. 58.

4 Alumina and oxide of iron remain; dissolve in muriatic acid and add to the solution (6).

No. VI.

ACTION OF GYPSUM.—*See Part III., pp. 47 to 51.*

In the text I have stated what appear to me the most probable effects which gypsum is fitted to produce upon the soil. Some of the numerous opinions that have been entertained upon this point are thus summed up by Hlubeck:—

"According to *Köllner*, the action of gypsum depends upon the power possessed by lime to form with the oxygen and carbon of the atmosphere compounds which are favourable to vegetation; according to *Ruckert*, it acts like any other food; according to *Mayer* and *Brown*, it merely improves the physical properties of the soil; while, according to *Riel*, it is an essential constituent of the plant. *Hedwig* called gypsum the saliva and gastric juice of plants; *Humboldt*, *Girtaner*, and *Albert Thaer* considered it as a stimulant by which the circulation of plants is promoted; and *Chaptal* ascribed its action to a supposed power of supplying water and carbonic acid to plants. *Davy* regarded it as an essential constituent of plants, because it acts only where gypsum is wanting in the soil; while other English agriculturists have supposed it to promote fermentation in the soil. According to *Laubender*, it acts as an exciting power without mixing itself with the sap of the plant; according to *Liebig*, it fixes the ammonia of the atmosphere; and, according to *Braconnot* and *Sprengel*, it supplies sulphur for the formation of the legumin of the leguminous plants (the most probable view)."—*Ernährung der Pflanzen*, p. 70, note.

To the above extract I may add, that Mr. Cuthbert Johnson, so long known for his many valuable writings upon agriculture, in following out the above idea of Reil and Davy in a recent paper on the use of gypsum (Jour. of the Royal Agr. Society, ii., p. 108), has stated that a crop of clover or sainfoin contains 1½ to 2 cwt. of gypsum per acre, exactly the quantity which the farmers of Kent and Hampshire find it useful to apply to their grass lands every year. This statement affords a very simple explanation of the use of gypsum, and one which at first sight leaves nothing to be desired. But it proves too much, for it supposes the whole of the gypsum which is laid upon the grass or clover field to be removed year by year in the crop, and makes no allowance either for the quantity which must necessarily be carried off by the rains, or for that which must be sometimes at least laid on in the form of farm-yard or other similar manure. Nor does the result of analysis confirm the above statement as to the quantity of gypsum contained in the crop of clover or sainfoin. By referring to Part II., p. 323, it will be seen that 1000 lbs. of dry hay do not contain, on an average, more than 4 lbs. of sulphuric acid—equal, supposing it all to be in combination with lime, to 8⅔ lbs. of gypsum. Or a crop of 1½ tons of hay contains the elements of about 30 lbs. of gypsum—only about a sixth part of what is usually added as a top-dressing to the land.

No. VII.

SUGGESTIONS FOR EXPERIMENTS WITH THE SOLUBLE SILICATES OF POTASH AND SODA.

In the text (Part II. p. 304 and Part III. p. 72) I have had frequent occasions to refer to the presence in the soil of the silicates of potash and soda, and to their supposed action in supplying silica to the stems of the grasses and of the corn-bearing plants. It would be interesting, in a theoretical point of view, to ascertain, by experiment, more fully than has hitherto been done, how far the application of these substances to the growing crops would, as a general rule, improve or otherwise affect their growth. But as those experiments which have already been made (Part III. p. 72), afford a strong presumption in favour of their economical value, it becomes a matter of practical interest also to investigate their apparent effects upon each of our cultivated crops.

These experiments are placed within the reach of the practical farmer during the ensuing season, by the introduction of the above compounds into the market at a reasonable rate (Part III. p. 73.) I therefore subjoin a few suggestions for experiments with these silicates, in the hope that some of the many zealous and intelligent practical men, who are now directing their attention to the applications of chemical science to agriculture, may be induced to enter upon this field of inquiry during the ensuing spring.

1°. In order to convey silica into the plant, it appears to be chemically indifferent whether the silicate of potash or that of soda be placed within reach of its roots. But as the silicate of soda can be manufactured very much cheaper than that of potash, it is desirable above all to try the effects of this compound—upon the grasses and corn-bearing plants especially.

2°. But as in the ashes of most plants potash is found in larger quantity than soda, it is *possible* that the effect of the silicate of potash upon some soils may be so much greater than that of the salt of soda as to counter-balance the difference of expense. Hence the propriety of extended trials with this compound also.

3°. But as in the ashes of all our cultivated plants *both potash and soda* are found, it may be that a mixture of the two silicates may act better than either alone. It will be proper, therefore, to apply such a mixture in different proportions, and to compare its effects with those of each of the silicates laid on singly.

The first series of comparative experiments, therefore, would be as follows:—

Silicate of Soda.	⅓ Silicate of Potash. ⅔ Silicate of Soda.	Nothing.
Silicate of Potash.	⅔ Silicate of Potash. ⅓ Silicate of Soda.	

The application may be from 1 cwt. to 1½ cwt. per acre, laid on as a top-dressing in moist weather early in the spring. Or it may be mixed with a large quantity of water, and applied with a water cart. In either case it ought to be in a state of a fine powder.

But although the above applications produce a beneficial effect upon the crops, it will not necessarily follow that the silica, which the *silicates* contain, has had any share in bringing about the good result. By mere exposure to the air for a length of time the potash or soda of those silicates will absorb carbonic acid from the atmosphere, and be converted into carbonates. The same will take place more rapidly still in the soil, where carbonic acid abounds. This conversion of the alkali into carbonate will set free a large part of the silica—in a state it is true in which it is in some degree soluble in water (Part II. p. 303)—but in which, nevertheless, it will find its way into the plant with much more difficulty than if it had remained in the state of a soluble silicate.

Now as the *carbonates* of potash and soda are known to promote vegetation (Part III. p. 40)—though even with these sufficient trials have not yet been made—it is possible, as I have remarked above, that a good effect may follow the application of the silicates, and yet it may be altogether due to the action of the carbonates which are formed by their decomposition. It is of consequence to ascertain if this really be the case, because the quantity of carbonates which would be formed by the decomposition of the silicates could be laid on directly at one-half of the price at which the silicates can as yet be sold.

The second series of comparative experiments, therefore, which it would be interesting to try, would be such as the following:—

Silicate of Potash, 1 cwt.	Crude Potash or Pearl Ash, 75 lbs.
Silicate of Soda, 1 cwt.	Crystallized Carbonate of Soda, 150 lbs.

The quantities here indicated are by the acre—that of carbonate of soda is given so great, because this salt contains upwards of three-fifths its weight of water (Part II., p. 317).

Another consideration ought not here to be omitted. Nature, as has been frequently illustrated in the text, feeds her plants with a mixture of many different substances, and by the aid of such mixtures they always thrive the best. The full benefit of the silicates, when applied alone, will be experienced only when every other ingredient which the plant requires is already present in the soil, and in sufficient abundance. But this can rarely be the case. Its success will be more sure, therefore, if it be applied in a state of mixture with other saline substances which are known to be more or less useful to vegetation, and which will not, upon admixture, decompose these silicates. Such are common salt and the sulphate and nitrate of soda.

A third series of comparative experiments, therefore, might be made, in which from 1 to 1½ cwt. per acre of the following mixtures might be applied ;—1°. Equal weights of common salt, of *dry* sulphate of soda, of nitrate of *soda*, and of silicate of *potash*. 2°. Equal weights of the same substances, omitting the silicate of potash. 3°. Equal weights of common salt, of *dry* sulphate of soda, of nitrate of potash, and of silicate of *soda* ; and 4°. Equal weights of the same substances, omitting the silicate of soda, or substituting carbonate of soda in its stead.

The sulphate of magnesia (Epsom salts) or of lime (gypsum) cannot be safely used along with the silicates, as the magnesia or lime they contain may decompose the silicates—forming sulphate of potash or soda and silicate of magnesia or lime, in which the silica is insoluble, and could not, therefore, until a further chemical change took place, find its way into the roots of the plant.

No. VIII.

RESULTS OF EXPERIMENTS IN PRACTICAL AGRICULTURE, MADE IN 1842.

I have much gratification in laying before my readers the results of a second year's series of experiments undertaken in consequence of suggestions thrown out in previous parts of this Appendix, or of opinions expressed in the body of the work. It is one of the numerous good results which have followed from the issue of these Lectures in a periodical form that I have the pleasure of incorporating in the same volume the results of experiments made during two successive years. No one who studies with care the experiments which follow, and the few remarks I have appended to them, will hesitate in pronouncing them to be as a whole the most valuable contributions to accurate experimental agriculture ever hitherto published. The results are not all equally important, nor all equally instructive, but they are the first fruits of a new line of research, which will lead us hereafter

to the discovery of important ge
practical men are now on the righ
tific knowledge now is among the
is no fear of their hereafter being p

A.—EXPERIMENT

I. The first series of experiment
obtaining answers to these two que

1°. *What are the relative effe
upon the turnip crop under th*

2°. *How far may these substan
sede farm-yard manure in th*

Turnips grown in Salter's Bog.—Field furrow-
applied partly in drills before sowing on
28th July, 1842. The salt and nitrate o
water; the others applied dry. *The qua
teenth of an acre.*

No.	Description of Dressing.	Quantity of manure ap		
		1st June.	28th July.	T
		lbs.	lbs.	
1	Nothing,........	—	—	
2	Common Salt,...	2	6	
3	Common Salt,...	—	4	
	Rape-dust,......	67	—	
4	Nitrate of Soda,.	2	6	
5	Nitrate of Soda,.	—	4	
	Rape-dust,......	67	—	
6	Nitrate of Soda,.	2	6	
	Sulphate of Soda,			
7	Sulphate of Soda,	2	6	
8	Sulphate of Soda,	—	4	
	Rape-dust,......	67	—	6
9	Rape-dust,......	67	67	13
10	Guano, ...	8	9	1
11	Soot, ...	bush. 1½	bush. 1	bu

The foregoing experiments were m
Blantyre on the home-farm, at Lennox
have been reported to me, at his Lor
liam Goodlet, under whose immediat
were conducted.

The reader will not suppose, becaus
monly called *failures*, that therefore th
contrary, they so far satisfactorily ans
intended to solve. They show

1°. That saline manures in that locality cannot economically take the place of farm-yard manure, even for a single season.

2°. That saline manures are even hurtful in the present condition of the land, when employed alone—producing a smaller crop than if no manure had been applied at all, and some of them in a remarkable degree. This appears to be especially the case with common salt, which, at the rate of 1 cwt. an acre, reduced the crop of bulbs nearly to one-half of what was yielded by the unmanured portion of the field. It is still more striking that nitrate of soda applied at the same rate should diminish the crop though in a less degree than common salt—and that soot should almost kill it entirely, and that 15 cwt. of rape-dust per acre should produce scarcely any effect. In regard to guano it was applied in too small quantity to do all the good of which it was capable had it been laid on more largely. If 6 or 8 cwt. instead of 1½ cwt. per acre had been used, the crop would probably have equalled that obtained by the use of farm-yard manure.

There is no doubt that to the extreme drought of the season, as Mr. Goodlet observes, must be ascribed the injury or actual lessening of the crop in this case, by the use of saline manures. The drought brings up the saline matter to the surface, and thus enables it to encrust, and weaken, or entirely kill, the growing plants. The want of rain in 1842 was much more felt in the Eastern part of Scotland than in the West, where the greater part of the succeeding experiments were made, and where occasional showers refreshed the land.

One other observation I may make. Had the saline matters been mixed with a fair proportion of farm-yard manure, it is probable that even on this field the effects would have been very different. One reason for this expectation is, that the plants being kept in a rapidly growing state—partly use up, and even eagerly appropriate, a large portion of the saline matter as it rises to the surface—and by their strength are enabled to resist the injurious action of any excess, which in ordinary circumstances is likely to remain. The reader, however, will not ask why the experiments were not so made—for he has already seen that their object was to ascertain the effect of saline manures *applied alone*. From their results, however, he will draw for himself the important practical rule, that *in ordinary circumstances it is unsafe to trust his turnip crop to saline manures alone*—that they may assist the action of farm-yard or other similar mixed manures, but cannot supply their place. But upon this point the succeeding series of experiments throw much further light.

II. The special object of the following four series of experiments was to ascertain—

1°. *The relative effects chiefly of various mixed manures upon several varieties of turnips;* and

2°. *Whether any of these mixtures could alone be economically used to supersede farm-yard manure.*

They were made at the home-farm at Barochan, near Paisley, under the direction and superintendence of Mr. Fleming, whose excellent experiments, made in 1841, are recorded in a previous part of this Appendix (pp. 27 to 36.) Mr. Fleming describes himself as much indebted to his overseer, Mr. Gardiner, without the aid of whose zeal, intelligence, and careful superintendence, so numerous a body of experiments could neither have been made, nor the results accurately ascertained.

1°. Comparative Experiments with various substances used as manures, for growing *Swedish Turnips;* seed sown 6th June, bulbs lifted 25th Nov., 1842.

No.	ORCHARD FIELD. Description of Manures used.	Quantity applied per imperial acre.	Produce of Bulbs, topp'd & tail'd per ⅛ im. acre.	Produce of Bulbs, topp'd and tail'd, per imperial acre.			Cost of Manure per im. acre, including carriage & putting on.		
			lbs.	tons.	cwt.	qrs.	£	s.	d.
1	Peat and Night-soil, mixed.....	20 tons.	4800	17	2	3	6	12	0
2	Gypsum.........................	5 cwt.	4080	14	11	2	0	12	6
	Carbonate of Lime.............	20 bush.	4640	16	11	2	0	3	0
3	Sulphate of Ammonia	1 cwt.	4320	15	8	2	1	12	0
	Quick-lime	20 bush.							
	Soot............................	20 bush.							
4	Sulphur	6 lbs.	3980	14	13	1	0	2	0
5	Imitation of Daniel's mixture...	50 bush.	4400	15	14	1	0	15	0
6	Wood Charcoal Powder	50 bush.	4240	15	2	3	2	10	0
7	Fresh Animal Charcoal	10 cwt.	5920	21	2	3	2	10	0
8	Exhausted Animal Charcoal....	10 cwt.	5560	19	17	1	2	0	0
9	Turnbull's Humus...............	50 bush.	4800	17	2	3	2	10	0
10	Bones diss. in Muriatic Acid....	10 cwt.	5200	18	11	3	3	0	0
11	Barochian Artificial Guano......	3 cwt.	4960	17	14	1	1	10	0
12	Turnbull's do. do.........	3 cwt.	4080	14	11	2	1	4	0
13	Natural Guano	3 cwt.	6560	23	8	2	3	15	0
14	Salt and Quick-lime mixed, 3 months old...............	50 bush.	4240	15	2	3	0	15	9
15	Soot.............................	50 bush.	4480	16	0	0	1	0	0
16	Potash and Lime mixed, 14 months old...............	50 bush.	4400	15	14	1	1	17	6
17	Quick-lime	50 bush.	3200	11	8	2	0	9	9
18	Wood-ashes	50 bush.	3600	12	17	1	1	5	0
19	Bone-dust	40 bush.	4160	14	17	1	5	10	10
20	Rape-dust	1 ton.	4000	14	5	3	8	10	0
21	Woollen Rags	1 ton.	3920	14	0	0	9	9	0
22	Farm-yard Dung................	20 tons.	5200	18	11	2	10	10	0
23	Nothing		3440	12	5	3			

Remarks.—The land is a light loam, loose in texture, and of a light brown colour. Subsoil hard, and full of small stones: it is of as nearly as possible the same quality. The turnip seed was all sown upon the same day. Rain came on the night after sowing, and in consequence the crops brairded well, and came away strong. Those which show the greatest weight in the Table kept the lead of the others all the season. The numbers of the plots in the Table are placed in the order in which they followed each other on the ground. The crop would probably have been larger had there been more rain.

2°. **Results of Experiments with various Substances used as manures for growing *Early Liverpool Yellow Turnips*, sown 9th June, and lifted 2d December, 1842.** *The quantity of land in each plot was one-eighth of an imperial acre.*

No.	BERRIE KNOWES FIELD. Description of Manures used.	Quantity of Manure applied per imperial Acre.	Cost per Acre, including carriage and putting on.			Produce of Bulbs, topped and tailed, per imperial Acre.		
			£	s.	d.	tons.	cwt.	qrs.
1	Natural Guano at 25s.	5 cwt.	6	5	0	32	2	2
	Wood-ashes	20 bush.	0	10	0			
2	Barochan Artificial Guano*	5 cwt.	2	10	0	21	2	3
	Wood-ashes	20 bush.	0	10	0			
3	Rape-dust	15 cwt.	6	10	0	24	11	2
4	Turnbull's Artificial Guano	5 cwt.	2	1	6	18	5	3
	Wood-ashes	20 bush.	0	10	0			
5	Soil Simple					11	8	2
6	Turnbull's Humus	50 bush.	2	11	6	13	14	1
7	Bone-dust	30 bush.	4	3	6	17	2	3
8	Potash and Lime mixed, 14 months old	50 bush.	1	17	6	14	5	3
9	Salt and Lime mixed, 3 months old	50 bush.	1	0	0	18	17	1
10	Sulphate of Magnesia,	1 cwt.	0	8	0	14	17	1
11	Sulphate of Ammonia	1 cwt.	1	1	0	24	11	2
12	Nitrate of Soda	1 cwt.	1	5	0	27	2	3
13	Sulphate of Ammonia	56 lbs.	0	11	0	20	17	3
	Wood-ashes	40 bush.	1	0	0			
14	Nitrate of Soda	56 lbs.	0	12	6	11	11	2
	Sulphate of Magnesia	28 lbs.	0	2	6			
	Wood-ashes	40 bush.	1	0	0			
15	Sulphate of Ammonia	84 lbs.	0	16	0	16	14	1
	Sulphate of Magnesia	40 lbs.	0	3	4			
	Lime and Potash	20 bush.	0	8	0			
16	Turnbull's Artificial Guano	5 cwt.	2	1	6	21	4	1
17	Barochan Artificial Guano	5 cwt.	2	10	0	24	2	1
18	Soil Simple					12	17	1

Remarks.—The soil is a light hazel loam incumbent upon sand-stone rock. It was trenched with the spade, in the spring of 1842, out of the pasture grass, to the depth of 16 inches, and the rock quarried out when it came nearer the surface than that depth, it was again pointed over before sowing, after which the drills were made upon the flat surface with the hoe, at the distance of 27 inches between them, *the manure sown in by the hand*, and covered up, the seed sown and rolled in. The weather was very dry at the time they were sown, and continued so till about the 20th June, accompanied with east winds and bright sunshine. They brairded moderately well, and most of them came away strong and healthy. In examining them, and in the working them, which was done by the hand-hoe, many of them showed a remarkable difference from the others; particularly *No.* 1 *was pre-eminent above the others for size of bulbs and strength of foliage.* Many of the bulbs were 11 lbs. in weight; those with the saline and alkaline manures, such as Nos. 8, 9, 10, and 12, were much smaller in bulbs and leaves than No. 1, *but were remarkable for firmness and solidity of bulbs.* No. 11 was larger in size both of bulbs and leaves, but soft and light in weight. No. 7 had very firm solid bulbs, as had also Nos. 2 and 4. The numbers of the plots given in the Table indicate the order in which they were grown in the field.

* The *Barochian Artificial Guano* consisted of

Bones dissolved in Muriatic Acid	2 cwt.
Charcoal powder	2 cwt.
Sulphate of Ammonia	1 cwt.
Common Salt and Gypsum, each	1 cwt.
Wood-ashes	5 cwt.
Nitrate of Soda	28 lbs.
Sulphate of Soda and Sulphate of Magnesia, each	10 lbs.
	12 cwt. 1 qr. 20 lbs.

See note to page 71.

3°. Experiments with various Manures on nine Acres of Turnips on the Farm at Crooks, 1842.

No.	Date of Sowing.	Quantity of Land per Scotch Acre.		Manures, and quantities applied to the land sown, per Scotch Acre.	Produce in Tons per Scotch Acre.	Kinds of Turnip.	Value of Manures applied.		REMARKS.
		A.	R.				£	s.	
1	May 28.	1	1	Rape-dust 5 cwt., Humus 25 bushels, Bone-dust 12 bush., Peat ashes 5 carts	22	Swedes	4	15	Soil a stiff loam, moist, and in good order; when the seed was sown, it brairded well, and came away at once.
2	May 30.	1	0	Rape-dust 5 cwt., Bones 10 bushels, Humus 25 bush., Ashes 5 carts......	20	Do.	4	10	Soil rather lighter than the former; seed brairded well, and came away at once.
3	June 9.	1	2	Johnstone town-dung 30 tons at 6s., Bones 14 bush. at 2s. 6d...........	24	Yellow.	10	15	Soil the same as above; brairded quickly in consequence of a shower of rain.
4	June 11.	0	3	Farm-yard dung 25 tons at 7s., Bones 10 bush. at 2s. 6d..................	19	Do.	10	0	Soil lighter than No. 3; a bad braird, and turnips long of springing for want of rain.
5	June 15.	1	0	Artificial Guano (No. I., p. 76) 2 cwt., Humus 40 bush., Peat Ashes 5 carts.	20	Do.	3	5	Soil as above; long of brairding in consequence of want of rain.
6	June 17.	1	1	Natural Guano 1 cwt., Humus 40 bushels,..............................	18	Do.	2	15	Soil as above; and like No. 5, still very dry for want of rain; a late braird.
7	June 28.	1	1	Humus 57 bush., Bones 10 bush....	14	Do.	4	2	Soil lighter, mixed with peat; no rain—bad braird.
8	July 4.	1	1	Artificial Guano mix., (No. II., p. 76)	12¼	White.	5	12	Soil heavy clay loam; no rain, and a bad braird. The two latter, from drought and late sowing, did not grow much till the end of September; and when checked by frost in the beginning of November, were still growing vigorously.

N. B. The land was of different qualities, the seed also sown at various times, and in very different states of the atmosphere, with respect to moisture, yet the average produce was good; and although it is not easy to say which of the artificial manures, under such circumstances, was actually the best, the general result shows that any of these used will produce on my land a good average crop of turnips, and at a less expense than farm-yard manure, and tends to confirm the correctness of various experiments tried by me on a smaller scale. The measurements having been made by the Scotch chain; I have not altered them. No. 8 would probably have been the best turnips, had they been sown earlier, and been assisted by a fall of rain.

4°. Results of Experiments with different mixed manures, in growing *White Globe Turnips*, on new trenched land, Bucklather Field. Sown 13th July, and lifted 16th December, 1842.

No.	Description of Manure used.	Quantity per imperial Acre.	Price of Manure per Acre.			Weight in imperial pounds per ⅛th Acre.	Weight in tons, &c., per imperial Acre.	
			£	s.	d.	lbs.	tons.	cwt.
1	Turnbull's Humus...........	60 bush.	3	0	0	5950	21	5
2	Turnbull's improved Bones..	5 cwt.	1	10	0	4900	17	10
3	Barochan artificial Guano....	5 cwt.	2	10	0	6300	22	10
4	Natural Guano..............	5 cwt.	6	5	0	9170	32	15

The Natural Guano was purchased December, 1841, when the price was £25 per ton. It can now be had for £12.

Remarks.—The land was drenched 18 inches deep, and completely drained at the distance of 18 feet, with tile drains laid 30 inches deep, in February, 1842. Previous to this it was in a wet, sour state. It was again pointed over with the spade, and the drills made for the manures with the hoe upon the level surface. The manures were then sown in the bottom of the drills with the hand, and a little earth being put over them, the seed was sown, covered, and rolled. The weather had been dry for some time before sowing, but rain came on that day; they brairded quickly, and continued to grow till lifted—the field being well sheltered. The tops of Nos. 2, 3, and 4 were of a dark green colour, and remarkably luxuriant, many of the bulbs weighing from 5 to 8 lbs. No. 1 was of a lighter green, but strong and healthy, and many of the bulbs of this lot were 5 and 6 lbs. The bulbs of all of them were finely shaped.

III. The object of the two following series of experiments was the same as in those of Mr. Fleming.

1°. Results of comparative experiments upon *Swedes* and *other Turnips* made on the home farm of Mr. Alexander, of Southbar, near Paisley, in 1842.

The soil of the field was a deep loam, with a slight admixture of peat—the subsoil was partly a light clay and partly a sandy gravel. It was thoroughly tile-drained and subsoiled to the depth of fourteen inches.

No.	Kind of Manures.	Quantity per imperial Acre.	Cost per imperial Acre.		Produce in bulbs per imp. Acre.
			£	s.	
	Swedes, *sown 8th May.*				
1	Bone-dust....................................	32 bush.	4	8	24 tons.
2	Bones..	16 bush.	5	8	28 tons.
	Ash-dung.....................................	12 tons.			
3	Farm-yard dung	32 tons.	11	4	30½ tons.
	Mixture of Yellow and White, sown 10th July.				
4	Guano..	3½ cwt.	3	10	20 tons.
5	Guano..	2 cwt.	4	16	24 tons.
	Farm-yard manure..........................	8 tons.			

Mr. Alexander adds, I must here notice particularly the result of the last two experiments. The seed sown was a mixture of yellow and white, and the period of sowing as late as the 10th of July. The weather at the time being favorable, they brairded quickly, grew with great vigour, and when all the other turnips in the field became affected with mildew they stood as green as ever. This (viz., the non-mildewing) I attribute greatly to the guano, as well as to the late sowing, never before having seen such a weight of turnips produced, sown so late in the season. I applied other artificial manures on both of these fields with a due proportion of dung, varying the quantities and modes of application, as appeared to me best to test their qualities, but as the comparative effect is so difficult to decide upon, I can only here observe, with any certainty, that though the turnips brairded quicker when the dung was assisted with these manures, *particularly where Turnbull's humus was applied*, the crops afterwards did not appear to me to be materially aided.

2°. Result of experiments upon *Yellow Turnips* made by Mr. Alexander, of Southbar, at Wellwood Farm, Muirkirk, Ayrshire, 1842.

The nature of the soil on which the experiments were made was reclaimed moss (then about 2 feet deep), having a clayey subsoil, but which had been thoroughly drained with tiles at fifteen feet apart. The field had produced white and hay crops, but, as far as known, had never been previously green-cropped. The whole of it received the same labour, preparatory to sowing, and the weather during the operation (which lasted four days) was the same, thus giving to each experiment an equal chance. The period of sowing was from the 15th to 19th of May; the turnip seed used was Skirving's improved purple-topped yellow; the dung used was the produce of the farm, and, with the exception of the foreign guano, all the other manures applied were those manufactured and sold by Mr. Turnbull, of Glasgow. *The extent of ground for each experiment was one acre, Scotch measure.*

No.	Kind of Manure.	Quantity per imperial Acre.	Cost of manure per imperial Acre.	Produce in Bulbs per imperial Acre.	Cost for Manure per ton.
			£ s. d.		s. d.
1	Farm-yard Dung	12 tons.	4 4 0	28 tons.	3 3½
	Humus	2 cwt.	0 8 0		
2	Farm-yard Dung	12 tons.	4 4 0	24 tons.	4 1
	Humus*	1¾ cwt.	0 7 0		
	Artificial Guano*	1½ cwt.	0 6 0		
3	Farm-yard Dung	12 tons.	4 4 0	20 tons.	4 11½
	Prepared Bones*	2½ cwt.	0 15 0		
4	Farm-yard Dung	12 tons.	4 4 0	16 tons.	6 7½
	Humus	90 lbs.	0 3 9		
	Improved Bones	90 lbs.	0 4 10		
	Artificial Guano	90 lbs.	0 5 6		
	Ammoniacal Salts	45 lbs.	0 8 0		
5	Artificial Guano	3¼ cwt.	1 3 0	9½ tons.	2 5
6	Guano	3¼ cwt.	3 5 0	28 tons.	2 4

IV. *Effect of Gypsum on the Turnip Crop.*

In 1841, Mr. Burnet, of Gadgirth, near Ayr, applied a top-dressing of gypsum to part of a field of turnips, and found *that it nearly doubled the crop.*

In 1842, Mr. Campbell, of Craigie, in the same neighborhood,

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* *Turnbull's Humus* is formed from urine and night-soil mixed with gypsum and charcoal and then dried.

Turnbull's prepared Bones are bones and flesh dissolved in muriatic acid, and mixed with about an equal quantity of charcoal in powder.

Turnbull's Artificial Guano is, I believe, prepared bones, with a little salt and sulphate of ammonia prepared from urine, and dried with a stove-heat.

"dressed a six acre field, with the exception of a few rows, with two cwt. of unburned gypsum per acre. The crop over the whole was excellent, but there was no perceptible difference between the dressed and the undressed part."

How are these discordant results to be reconciled? The following questions suggest themselves as worthy of investigation—

1°. *Is gypsum really propitious to the turnip crop,—and to every variety alike?*

2°. Are the unlike results above obtained to be ascribed to the abundant presence, in the one case, of gypsum in the soil, or in the manure ploughed in, and its absence in the other—or to the variety of turnip cultivated?—or

3°. Can the sea-spray supply gypsum to Mr. Campbell's estate, which is within two miles of the coast, while it is less bountiful to that of Mr. Burnet, which is six miles inland?

B.—EXPERIMENTS ON POTATOES.

I. Results obtained by Mr. Campbell, of Craigie.

Four equal drills of potatoes were treated as follows:—

1°. Guano, 3 cwt. per acre, - - -	produce 5 pecks.
2°. Farm-yard dung, 40 cubic yards per acre -	produce 6 do.
3°. Do., top-dressed afterwards with 60 lbs. of nitrate of soda, - - -	produce 6 do.
4°. Do., top-dressed with 160 lbs. of sulphate and nitrate, mixed, - -	produce 6 do.

The above result is favourable to guano, considering that it was applied in such small quantity; but why did the saline manures produce no effect—was it because of the drought of the season, or was it because Mr. Campbell's land is already amply supplied with salts of soda from its vicinity to the sea? (see *Lectures*, Part III, pp. 63 and 67). These experiments are not unworthy of repetition on a larger scale.

II. Some very striking results, obtained by top-dressing potatoes with saline manures on a small scale, were described by Mr. Fleming, of Barochan, in 1841, and are recorded in the preceding part of this Appendix (p. 32). The following three series of experiments, made under the direction and superintendence of the same gentleman, have been made upon a larger scale, and with the view of throwing light upon a greater number of interesting points—

The object of the first series was to ascertain the effect—

1°. *Of different mixed manures, when applied alone to the potato crop.*

2°. *Their relative effects on different varieties of potato.*

Comparative Experiments with various substances used as manures for growing potatoes, planted 18th May, and lifted 12th October, 1842. *The quantity of land in each plot was one-sixteenth of an imperial acre.*

No.	Description of Manures used, and kinds of Potatoes.	Quantity of Manure applied per imperial acre.	Produce in bolls (of 5 cwt. each), Renfrewshire measure, per imperial acre.			Produce in Tons, &c. per imperial acre.			Cost of Manure per acre, including carriage and putting on.		
			bolls.	pks.	lbs.	tons.	cwt.	qrs.	£.	s.	d.
	A.—*White Don Potato.*										
1	Turnbull's Humus .... Wood-ashes, mixed	30 bushels 30 bushels	45	11	15	11	8	2	2	7	0
2	Rape-dust	1 ton ...	49	5	33	12	6	2	8	12	0
3	Turnbull's prepared Bones	3 cwt. ...	34	14	2	13	14	1	0	18	0
4	Turnbull's artificial Guano	3 cwt. ...	43			10	15	0	1	4	0
5	Natural Guano	3 cwt. ...	73	13		18	9	0	3	17	0
	B.—*Red Don Potatoe.*										
6	Soil, simple	...	27			6	15	0			
7	Wood-ashes	50 bushels	30	2		7	10	2	1	5	0
8	Natural Guano	4 cwt. ...	57	6		14	6	5	5	0	0
9	Natural Guano and Wood-ashes	4 cwt. and 25 bushels ashes.	63			15	15	0	5	12	6
10	Natural Guano, Wood-ashes, and Wood-charcoal.	4 cwt. and 20 bushels charcoal.	70			17	10	0	6	0	0
11	Turnbull's artificial Guano	4 cwt. ...	51			12	15	0	1	12	0
12	Turnbull's artificial Guano and Wood-ashes	4 cwt. and 25 bushels ashes.	51			12	15	0	2	4	6
13	Turnbull's prepared Bones and Wood-ashes	4 cwt. and 25 bushels ashes.	54	14	2	13	14	1	1	16	6
14	Turnbull's prepared Bones	4 cwt. ...	51			12	15	0	1	4	0
15	Rape-dust	1 ton. ...	40			10	0	0	8	12	0
16	Rape-dust and Wood-ashes	1 ton and 25 bushels ashes.	56			14	0	0	9	4	6
17	Potash and Lime (1 lb. potash to 1 bushel lime) ..	60 bushels.	39			9	15	0	2	2	0
18	Gypsum	5 cwt. ...	39			9	15	0	0	12	6
19	Salt and quick-lime (4 cwt. salt to 1½ tons lime) ..	60 bushels.	34			8	10	0	1	0	0
20	Humus and Wood-ashes	40 bushels and 25 bushels ashes.	36			9	0	0	2	14	0
21	Bone-dust	45 bushels.	39			9	15	0	6	14	0
	C.—*Connaught Cups Potato.*										
22	Soil, simple	...	23			5	15	0			
23	Bone-dust	45 bushels.	39			9	15	0	6	14	0
24	Natural Guano	4 cwt. ...	54	14	2	13	14	1	5	1	6
25	Rape-dust	1 ton. ...	52			13	0	0			
26	Turnbull's Humus	50 bushels.	43			10	15	0	2	12	0

The above manures were put in with the potato cutting,—no top-dressing being afterwards applied.

2°. The object of the two following series of experiments was to ascertain—1°. The relative effect of different *saline substances applied along with farm-yard manure*; and—2°. Whether the effects were greater when *mixed with the manure* at the time of planting, or when subsequently applied, *as a top-dressing* to the growing plants.

1. Result of Experiments *with saline substances in top-dressing* Early American Potatoes. Planted 18th April, top-dressed 1st June, and lifted 28th September, 1842. Low Field, Barochan. *The quantity of land in each plot was one-eighth of an imperial acre.*

No.	Description of Top Dressing.	Quantity of dressing applied per imperial acre.	Produce in pecks of 35 pounds each.	Produce in bolls of 5 cwt. each per imperial acre.	Produce in tons, &c., per imperial acre.			Cost of dressing per imperial acre, including carriage and putting on.		
		cwt.	pecks.	bolls.	tons.	cwt.	qrs.	£	s.	d.
1	Nitrate of Soda	1½	128	64	16	—	—	1	11	0
2	Sulphate of Ammonia	1½	116	58	14	10	—	1	11	0
3	Sulphate of Magnesia,	1½	106	53	13	5	—	0	12	6
4	Nitrate of Potash	1½	148	74	18	10	—	2	3	0
5	Nothing but Dung	40 cubic yds.	98	49	12	15	—	0	0	0
6	Sulphate of Soda Nitrate of Soda	1¼ ¾	144	72	18	—	—	1	4	9
7	Sulphate of Soda	2	98	49	12	15	—	0	15	0
8	Sulphate of Soda Sulphate of Ammonia	1¼ ¾	151	75½	18	17	2	1	4	9
9	Sulphate of Magnesia Nitrate of Soda	1 1	180	90	22	10	—	1	9	0

Remarks.—The soil is a light loam of good quality, subsoil hard, stoney till, and retentive of water. The potatoes were planted with the spade at the distance of 26 inches between drills. The manure, farm yard dung at the rate of 40 cubic yards per acre, spread in the bottom of the drills—cut sets laid on this and covered up. (The cut tubers planted were the produce of those top dressed last season (see Appendix, page 32.) Came away strong and healthy, of a dark green colour, and were very remarkable from the contrast which they presented to the same variety of potato—planted alongside this experimental ground—that had not been dressed last season. These last came away weak, and of a yellowish green colour, and, under the same treatment in every respect, did not produce so good a crop by 15 bolls per acre). Nos. 1, 2, 4, 6, 8, and 9, had all the same effect in altering the colour of the stems and leaves to a darker green. Nos. 3 and 7 had not that effect, but No. 3 added greatly to the produce. No. 7 made no visible alteration, *but burned the tops severely at the time of dressing, as did most of the others this dry season*; thus burning was in most cases only temporary.

2°.—Results of Experiments with different *saline substances, mixed with farm-yard dung at the time of planting,* in growi Early American Potatoes. Planted 29th April, and lifted 31st August, 1842. *The quantity of land in each plot was one-eigh of an imperial acre.*

No.	Description of Manure and Salts.	Quantity applied per imperial Acre.	Produce in Pecks, of 35 lbs. each.	Produce in Bolls, of 5 cwt. each, per Acre.	Produce in Tons, &c., per Acre.			Cost of Salts used, per Acre, including putting on, exclusive of Dung.*		
			Pecks.	Bolls.	tons.	cwt.	qrs.	£	s.	d.
1	Farm-yard Dung alone	35 cubic yards.	71	35½	8	17	2			
2	Common Salt, added to Dung	2 cwt.	70	35	8	15	0	0	4	0
3	Nitrate of Soda, do.	1½ cwt.	99	49½	12	7	2	1	12	0
4	Sulphate of Magnesia, do.	2 cwt.	91	45½	11	7	2	0	17	0
5	Sulphate of Ammonia, do.	1½ cwt.	107	53½	13	7	2	1	12	0
6	Sulphate of Soda, do.	2 cwt.	64	32	8	0	0	0	17	0
7	Silicate of Potash,† do.	1 cwt.	120	60	15	0	0			0

REMARKS.—The soil upon which the above were grown was a subsoil, the upper soil having been taken off at different times. It was trenched two feet deep in the spring of 1841, and which had to be done with the mattock, it being too hard for the spade alone, it was cropped that season with potatoes, manured with 40 cubic yards of compost of weeds, cut grass, and half-rotten leaves. It was again trenched to the same depth after the crop of potatoes was lifted; and was again planted in the spring of 1842 with potatoes, manured with 35 cubic yards of farm-yard dung, mixed in the proportions stated with the above salts. The potatoes were planted with the spade, at the distance of two feet between the drills, the manure being put in the bottom of the drills, the salts sown by the hand above it, and then all mixed together with a dung fork. The cut sets were laid upon the mixture and covered up. *As was remarked in 1841, the potatoes with No. 3 were eight to ten days brairded before the others; also Nos. 5 and 7 were earlier than the others, those three being all fairly up in drills before the others made their appearance through the ground.* Nos. 2, 4, and 6 were latest, and very irregular in coming up, and upon examining the drills a few of the sets appeared to have been burned. There was a marked dissimilarity in the stems and leaves of these potatoes through the summer. Nos. 3, 5, and 7, were all of a darker green colour and stronger than the others. No. 7 *was remarkable for intenseness of colour and length of stems,* so much so that it appeared to be a different variety of potatoe. No. 4 was fully better in appearance than Nos. 2 and 6, which were of a yellowish green colour and had a stunted appearance all the season. When this ground was first broken up, a pound of it was boiled in pure rain water and filtered, which was then evaporated, the residue weighed 4½ grains, mostly soluble salts, but hardly a trace of common salt.

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* Dung 5s. 6d. per cubic yard, exclusive of cartage and spreading.

† The silicate of potash or soluble glass was directly prepared from caustic potash and sand or silex fused together.

3°. The following experiments were made with the view of determining *how far economical mixtures might be made to supersede farm-yard manure in the growth of potatoes*:—

1°. Account of an Experiment in growing Potatoes (Irish Pink Eyes) with the following mixture of substances, instead of farm-yard dung, planted 20th April, 1842.

No.	Ingredients.	Quantity intended to manure four Acres.			Cost of Substances for four Acres.		
		cwts.	qrs.	lbs.	£	s.	d.
1	Rape-dust	5	0	0	1	10	0
2	Bones dissolved in Muriatic Acid	2	0	0	0	12	0
3	Sulphate of Magnesia	0	2	24	0	6	0
4	Carbonate of Lime	2	0	0	0	1	6
5	Nitrate of Soda	0	2	0	0	10	0
6	Common Salt	1	2	0	0	2	3
7	Sulphate of Soda	1	2	0	0	9	0
8	Sulphate of Ammonia	0	2	0	0	10	0
9	Sulphur	0	0	2	0	1	0
10	Dry Moss-earth	6	2	0		—	
		20	0	26	4	1	9

Remarks.—The above mixture was sown in the drills at the rate of about 5 cwt. per imperial acre, at a cost of little more than £1 sterling, and produced a fair crop of potatoes of a remarkably fine quality, 43 bolls per acre of imperial Renfrewshire measure, weighing 5 cwt. each, upon a poor and light, although new soil, but not worth more than 25s. per acre. Great caution is required in using this mixture, as it is very apt to burn the cut sets if laid directly upon them. A little earth should be put between the cut potato and the manure.

2°. The following mixture was made, and lay together for five weeks, when it was sown in the bottoms of potato drills upon a poor tilly soil, and White Don Potatoes, planted with it 30th April, 1842.

No.	Ingredients.	Quantity mixed to manure one Acre.			Cost of Substances for one Acre.		
		cwts.	qrs.	bush.	£	s.	d.
1	Saw-dust, mostly from Alder....			40		—	
2	Potash and Lime mixed, 14 months old...			10	0	7	6
3	Common Salts	1	2		0	2	3
4	Sulphate of Ammonia	1	0		1	0	0
5	Sulphate of Soda	0	2		0	3	6
6	Sulphate of Magnesia	0	2		0	4	0
7	Coal Tar, 20 gallons, say	—			0	10	0
		3	2	50	2	7	3

Remarks.—The potatoes planted with the above mixture came quickly through the ground, and were very luxuriant in foliage. They were lifted 15th October, after being cut down by frost whilst still unripe and growing. On being taken up, they were found to yield a produce of 56 bolls of Renfrewshire measure, weighing 5 cwts. each, per acre, of very fine potatoes, many of which weighed from 24 to 30 oz. each.

N. B. This mixture, after being put together, fermented, and was frequently turned, but kept dry.

The several series of experiments made upon potatoes by Mr. Fleming are deserving of careful consideration, and many of them of judicious repetition. They are all well contrived or devised, and each series skilfully arranged.

In agricultural experiments it is of the greatest possible consequence that the practical man should have a clear and definite object distinctly in view. If so, his experiments may be signally successful in his own estimation, while, economically considered, they may be total failures. This, as we have seen, was to a certain extent the case with the first series of experiments made upon Lord Blantyre's farm, as above detailed (p. 64.) The applications in some instances lessened the crop, but the result, nevertheless, threw considerable light upon the questions which the trials were intended to solve.

In making an experiment, the practical farmer *asks a question* of nature ;—in arranging the form and details of his experiment, he is putting together the words by which his question is to be expressed. If his question be clearly put, nature will give him, sooner or later, a clear and distinct answer—if he have skill enough in nature's language to understand what she has said to him. I say, sooner or later, for it may be sometimes necessary to repeat the question, either because something has intervened to prevent nature, so to speak, from hearing his question,—because it has not been accurately expressed—or because something in the seasons, or otherwise, has prevented her answer from being clearly understood—perhaps from being heard or read at all. Circumstances may even prevent the answer from not being given until a second summer come round, when, if we are on the alert, it may never be received at all.

The above experiments, as well as those which follow, form an excellent study for the practical farmer in reference to this matter. Every series is planned with a view to a given end, the circumstances are carefully noted before, during, and at the close of each of the several trials, 'and the answers are recorded with a very praiseworthy degree of accuracy. I shall place together, in one view, the most important of the deductions to which the experiments of 1842 appear to have led, when I shall have laid before the reader the whole of the tables which have as yet been placed in my hands.

C.—EXPERIMENTS UPON BARLEY.

The object of the following experiments, also made by Mr. Fleming, was to ascertain *the relative effect of different saline substances, when applied, as top-dressings, to a crop of white barley.*

The results, as shown in the last column, are sufficiently interesting.

Results of Experiments with various substances used as top-dressings upon Barley (common white,) The Barley sown 14th April, top-dressed 6th May, and cut down 25th August, thrashed, cleaned, measured, and weighed 5th October, 1842. *The quantity of land in each plot was one-eighth of an imperial acre.*

No.	RODEN HILL FIELD. Description of Top Dressings.	Quantity of dressing applied.	Weight in imperial pounds when cut in sheaf.	Amount of grain in imp. pounds when thrashed and cleaned.	Weight of straw when thrashed in imperial pounds.	Weight per bushel of grain fit for market.	Cost of Dressings.		Quantity of grain fit for market per imp. acre.	
		lbs.	lbs.	lbs.	lbs.	lbs.	s.	d.	bush.	lbs.
1	Nitrate of Soda	10	1821	364	500	56	2	0	52	0
	Common Salt	14					0	2¼		
2	Sulphate of Soda	21	1638	378	491	55	1	6	54	54
	Sulphate of Magnesia	7					0	5¼		
3	Natural Guano, at 25s.	42	2192	432	589	54	9	7	64	0
4	Nitrate of Potash	14	1665	255	590	54	3	6	37	42
5	Common Salt	42	1735	378	495	57	0	6½	53	3
6	Nothing....	—	1620	325	425	55	—		47	15
7	Turnbull's Artificial Guano	42	1925	334	480	54	3	0	49	26

Remarks.—The soil of this field is a light loam as nearly as possible uniform in quality, and had lain about ten years in pasture previous to the spring of 1842, when it was all trenched with the spade twelve inches deep. It had been thorough-drained with tiles some years before breaking up. After being trenched, it was dressed over, except where the experiments were, with two chaldrons of lime per acre, slaked with water, in which common salt had been dissolved, and before sowing the barley, with the exception of the experiment ground, it was top-dressed over with two and a-half cwts. of Turnbull's artificial guano per acre, *harrowed in as was also the top-dressing* No. 3, in the table of experiments. The barley was sown broad cast, 2¼ bushels per acre. Owing to the extraordinary drought at time of sowing, it did not braird well till rain came; after which it made rapid progress. Advantage was taken of heavy rains to put on the top-dressings, all of which were sown at the time above stated, viz., 6th May, except No. 4, which was not sown till the 17th, at which time *there was little rain, and, in consequence, it burned the plants, of which they did not recover all the season*, and the ground got full of weeds. No. 5 burned the plants also, but they recovered quickly, and gave a good return. *As was remarked before, wherever common salt was put on as a top-dressing on grain crops, either of wheat, barley, or oats, and on whatever description of soil upon this estate, the grain was invariably heavier per bushel, and had fewer weaks or tails in proportion to the quantity of grain per acre, than any of the other dressings applied here.* From the frequent mention of spade culture in these experiments, many may consider that they were upon a very small scale, which is not the case, the greater proportion of them being very extensive. Mr. Fleming, to give employment to the destitute labourers, having dug and trenched about thirty acres of land instead of ploughing it, which accounts for the frequent mention of spade culture, which, when it can be got executed at a moderate rate (particularly trenching at £4 per acre), is very advantageous, and seems superior to trench ploughing.

A. P. Gardiner.

D.—EXPERIMENTS UPON OATS.

The first of the following series of Experiments was made at Lennox-Love, at the request of Lord Blantyre, the second at Barochan, under the direction of Mr. Fleming. The general object of both was the same—*to ascertain the relative effect of different saline substances applied as top-dressings upon young oats;* but those of Mr. Fleming has, besides, *the special object of ascertaining the effect of certain mixtures upon oats when grown upon mossy land:*—

1°.—Oats, second crop, after old lea. Soil sharp loam; subsoil clay resting on sand-stone rock. Oats sown 14th March; top-dressings applied 13th May; crop cut 27th Aug.; and thrashed 9th Sept., 1842. *The quantity of land in each plot was one-eighth of an imperial acre.*

No.	Quarry Park, Lennox Love.	Manures.			Weight of produce as carted from field.	Weight as taken from thrashing mill of				Weight per bushel of Dressed Grain.	Quantity of Dressed Grain.	Increase of produce in Dressed Grain.	Decrease of produce in Dressed Grain.
	Description of Dressing.	Quantity applied.	Cost thereof.			Dressed Grain.	Grey or Seconds.	Straw.	Chaff, &c., unweigh'd.				
		lbs.	s.	d.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	bushels.	bush.	bush.
1	Nothing	—	—		672	264	8	362	38	39¼	6·75	—	—
2	Common Salt	14	0	4	588	239	13	323	13	40	6·00	—	·75
3	Common Salt .... Rape-dust....	7 112	7	0	644	236	24	328	56	40	5·95	—	·80
4	Nitrate of Soda	14	3	1	588	205	21	276	86	39½	5·19	—	1·56
5	Nitrate of Soda .... Rape-dust....	7 112	8	7	616	231	17	296	72	40	5·56	—	1·19
6	Nitrate of Soda .... Sulphate of Soda	7 7	2	0	504	187	12½	266	38½	30	4·81	—	1·94
7	Sulphate of Soda	14	1	0	504	188	11	249	56	39¼	4·82	—	1·93
8	Sulphate of Soda .... Rape-dust....	7 112	7	5	672	263	20	355	34	40¼	6·56	—	·19
9	Rape-dust....	224	14	0	616	224	26	324	42	40¼	5·62	—	1·13
10	Guano	28	5	0	938	351	30	496	61	40¼	8·75	2·00	—
11	Soot	4 bush.	4	0	532	193	11	269	59	37¾	5·12	—	1·63
12	Waste water from gas-work diluted with four times its bulk of water.	6 galls.	—		700	273	15	390	22	39¼	7·00	·25	—

8°—Results of Experiments *with various substances used as top-dressings upon Oats* (Sandy Oats), sown 16th April, *upon drained peat moss.* Nos. 2, 3, and 5, top-dressed on the same day; No. 1 dressed 6th May, cut down 14th September, and thrashed, cleaned, and weighed 6th October, 1842. *The quantity of land in each plot was one-eighth of an imperial acre.*

No.	SHAW PARK FIELD, BAROCHAN. Description of Dressing.	Quantity applied.	Weight in imperial lbs. when cut in sheaf.	Weight of grain in imperial pounds when thrashed & cleaned.	Weight of Straw when thrashed in pounds.	Weight per bushel of grain fit for market.	Cost of Dressing.		Quantity of Grain per imperial Acre fit for market.	
							s.	d.	bush.	lbs.
1	Sulphate of Ammonia	12½ lbs.	1105 lbs.	270 lbs.	490 lbs.	41 lbs.	2	6	52	18
	Water	20 gallons.								
2	Sulphate of Soda	21 lbs.	1220 lbs.	305 lbs.	450 lbs.	40 lbs.	1	8	61	0
	Nitrate of Soda	9½ lbs.					2	0		
3	Bones dissolved in Muriatic Acid ..	42 lbs.	1340 lbs.	320 lbs.	480 lbs.	42 lbs.	3	6	60	40
4	Nothing		960 lbs.	210 lbs.	320 lbs.	39 lbs.			43	3
5	Sulphate of Ammonia	7 lbs.	1600 lbs.	350 lbs.	620 lbs.	43 lbs.	1	4	65	5
	Silicate of Potash	14 lbs.					2	0		
	Sulphate of Soda	14 lbs.					1	2		
	Bones dissolved in Muriatic Acid ..	14 lbs.					1	2		

REMARKS.—The soil upon which the above were grown is moss, rather deeper in some parts than others, incumbent upon gravel of a stiff retentive quality. It had been partly drained some years ago, but owing to the nature of the soil the drains did not act well. In the spring of 1842, it was again drained with tiles, and trenched over with the spade to the depth of 16 inches, and some of the gravel subsoil brought up among the moss. The ground being divided into lots for the purpose, the top-dressings Nos. 2, 3, and 5 were sown on the 16th April, and slightly harrowed in; the oats were then sown and harrowed in. No. 1 was made from 160 lbs. sulphate of ammonia dissolved in 100 galls. of water (proportions for an imperial acre), and sprinkled upon the oats during the time of rain on 6th May. No. 5 was sown upon a lot where the moss was fully the deepest. They all brairded well; Nos. 2 and 5 coming rather earlier than the others, and of a darker colour, particularly No. 2. No. 1, after being watered with the solution, became also of a darker green, but neither Nos. 1 nor 2 were so strong in the straw as *Nos. 3 and 5, both of which were remarkable for strength and luxuriance, especially No. 5, which kept the lead of the others all the season.*

E.—EXPERIMENTS UPON WHEAT.

The following three series of Experiments upon wheat exhibit very interesting results :—

1°. The first series was made on the home home-farm of Lord Blantyre at Lennox Love, and was intended to ascertain *the relative effects in that locality of different, chiefly saline, manures applied as top-dressings to spring wheat.*

Spring Wheat after turnips, South-Lawn. Soil loamy clay; subsoil clay. Drained every furrow before breaking up from old grass in the autumn of 1839; *ploughed deep and subsoiled* in Spring of 1841. Wheat sown 5th February, 1842; manures applied 13th May; crop cut 24th August; and thrashed 10th September, 1842. *The quantity of land in each plot was one-eighth of an imperial acre.*

No.	LENNOX LOVE. Description of Dressing.	MANURES. Quantity applied.	MANURES. Cost thereof.	Weight of produce as carted from field.	Weight from Thrashing Mill of Dressed Grain.	Weight from Thrashing Mill of Grey or Seconds.	Weight from Thrashing Mill of Straw.	Weight from Thrashing Mill of Chaff, &c. unweighed.	Weight pr. bushel of dressed Grain.	Quantity of Dressed Grain.	Increase of produce in Dressed Grain.	Decrease of produce in Dressed Grain.
		lbs.	s. d.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	Bushels.	Bushels.	Bushels.
1	Nothing	—	—	1036	365	10	507	154	61⅓	5·956	—	—
2	Common Salt....	14	0 4	1008	349	20	547	92	61⅓	5·750	—	·296
3	Common Salt.... Rape-dust	7 112	7 0	1143	386	17½	610	134½	61⅝	6·250	·294	—
4	Nitrate of Soda .	14	3 1	1120	363¼	20¼	598	138¼	60¾	5·970	·014	—
5	Nitrate of Soda . Rape-dust	7 112	8 7	1176	394	17¾	648	116¼	61⅛	6·375	·419	—
6	Nitrate of Soda . Sulphate of Soda	7 7	2 0	1078	364	12	595	107	60¾	6·000	·044	—
7	Sulphate of Soda	14	1 0	896	286¼	11	483	115¼	60	4·750	—	1·206
8	Sulphate of Soda Rape-dust	7 112	7 5	980	339¼	10½	514	116½	61	5·563	—	·394
9	Rape-dust	224	14 0	1106	399	14	575	116	62¼	6·381	·425	—
10	Guano	28	5 0	1009	367	14	506	115	61¼	6·000	·044	—
11	Soot............	4 bush.	4 0	1036	361	14	564	97	60¾	5.939		·017

2°. The object of the second series, made at Barochan, was to ascertain the *relative effect of certain mixed, chiefly saline manures applied as top-dressings to winter wheat.*

Results of Experiments with various substances used as *top-dressings* upon Winter Wheat. Dressed 9th May, and cut 7th September, 1842. *The quantity of land in each plot was one-sixteenth of an imperial acre.*

No.	COOK'S FARM, BAROCHAN. Description of Top Dressings.	Quantity of Dressing applied.	Weight in imperial pounds when cut in sheaf.	Weight of grain in imperial pounds when thrashed and cleaned.	Weight of straw when thrashed in pounds.	Weight of clean grain per bushel.	Cost of Dressings.	Quantity of clean grain per imp. acre.	Weight of thrashed straw per imp. acre.
		lbs.	lbs.	lbs.	lbs.	lbs.	s. d.	bush. lbs.	lbs.
	Nothing	—	400	95	160	61	0 0	24 56	2560
1	Natural Guano....	21	540	116	230	60	4 4½	30 40	3680
2	Turnbull's Artificial Guano	21	420	95	175	61	1 8	24 56	2800
3	Common Salt	21	360	80	150	62½	0 4	21 27	2400
4	Sulphate of Soda .... Nitrate of Soda....	10½ 5½	480	101	190	61	0 8 1 0	26 39	3040
5	Common Salt .... Dissolved Bones	21 7	460	90	170	63	0 4 0 7	22 54	2720
6	Rape dust .... Sulphate of Magnesia	35 5½	510	110	200	62	2 7 0 6	28 24	3200

Remarks.—The soil is a heavy loam, incumbent upon a deep clay. The wheat was sown at the end of November, 1841, after a crop of yellow turnips. The turnips were manured with 20 tons of town dung per acre. Owing to the severity of the winter of 1841, and spring of 1842, the plants were very thin upon the ground. In April, 1842, it was sown down with grass seeds, harrowed and rolled, after which it tillered and gradually recovered. At the time the dressings were put on there was rain, but in general it was dry weather after, and in consequence the top-dressings did not produce such great results as they did in 1841. The field was examined from time to time, and the appearance of each experiment as noted down is fully borne out by the results given in the table, viz.:—No. 1 was taller in the straw, longer in the ear, and of a darker green colour than any of the others; No. 6 was next; and No. 4 was third. In point of appearance there was in the others no perceptible difference from the general crop, except No. 3, which appeared to have checked the growth of the plants, and from this check they scarcely recovered all the season. It is however remarkable, that wherever common salt was applied, the grain was heavier per bushel. *It will be observed, with reference to the experiment upon wheat, grown on this land last year, that the application of common salt had a very great effect, and would probably have also benefitted the general crop this year, had it not been for the extraordinary drought of the season* (see Appendix, p. 26.)

3°. The object of the third series, made by Mr. Burnet, of Gadgirth, near Ayr, was the same as those of Mr. Fleming. The mixtures employed, however, were different, and the tabulated results are at least equally interesting and satisfactory.

Results of Experiments with mixed manures used as top-dressings upon Winter Wheat (Eclipse variety), sown 29th October, 1841, and reaped 15th August, 1842. *The quantity of land in each plot was one-fourth of an imperial acre.*

No.	GADGIRTH, NEAR AYR. Manures applied 16th April.	Weight of traw.			Weight of Grain.			Weight of Grain, kiln dried.			Weight per bushel.	Light Grain.	Produce per acre in Grain		Value at 7s. per bushel.		Increased value in Grain.		Increased value in Straw.		Cost of application per acre.		128 lbs. of Grain produced in *fine flour*, as under.
		cwt.	qrs.	lbs.	cwt.	qrs.	lbs.	cwt.	qrs.	lbs.	lbs.	lbs.	bush.	lbs.	£	s.	£	s.	s.	d.	£	s.	lbs.
1	No application	7	1	18½	4	3	23½	4	0	16	61½	9	31	38	11	1	—	—	—	—	—	—	98
2	Guano ½ cwt. .... Wood-ashes	17	2	18	5	0	24	4	1	9	61	10	32	20	11	6	0	5	—	—	2	0	88
3	Artificial Guano, 1 cwt. .... Wood-ashes, 1 cwt.	6	3	25	5	0	17	4	1	10	59½	9	32	24	11	6	0	5	—	—	1	12	88
4	Sulphate of Ammonia, ½ cwt. Wood-ashes, 1 cwt.	8	3	21	6	2	7	5	1	10½	60	17	39	54	14	0	2	19	6	3	2	0	85
5	Sulphate of Ammonia, ½ cwt. Sulphate of Soda ½ cwt. .... Wood-ashes, 1 cwt.	11	0	18½	7	0	9½	6	2	8½	60	13	49	6	17	4	6	3	16	9	2	16	81
6	Sulphate of Ammonia, ½ cwt. Common Salt, ½ cwt. .... Wood-ashes, 1 cwt.	11	1	4	7	1	24	6	2	6½	60	9	49	0	17	3	6	2	17	3	2	4	84
7	Sulphate of Ammonia, ½ cwt. Nitrate of Soda, ½ cwt. ...... Wood-ashes, 1 cwt.	11	0	5	7	0	23	6	1	25	59	11	48	20	16	18	5	17	16	1½	3	4	70
8	Turnbull's Guano, 1 cwt. .... Sulphate of Lime, 1 cwt. .... Wood-ashes, 1 cwt	8	0	6	5	2	8	4	2	2	60	23	33	44	11	16	0	15	2	3	1	16	81

The soil a loam, with subsoil of clay; tile drained and trench-ploughed. Had been in beans the year previous, and had no manure with that crop nor with the wheat, except the above applications, harrowed in in spring. No. 6, at a cost of £2 4s., has produced an increase over No. 1 of £6 19s. 3d., being a *gain of* £4 15s. 3d.

F.—EXPERIMENTS UPON PASTURE AND OTHER GRASSES.

1.—Experiments made by Mr. Alexander, at Wellwood, in 1842.

A. On crops of *meadow and rye grass hay.*

1°. One Scots acre of well-drained mossy meadow, and full of timothy grass, was top-dressed during the last week of April, with 1 cwt. improved bones, ½ cwt. glauber salts, ½ cwt. of charcoal, all well mixed with ashes. RESULT.—Crop much improved, and came to 180 Ayrshire stones (of 24 lbs.) per acre. I may mention that this meadow suffered generally much from the severe drought; the above kept its growth best.

2°. One Scots acre of well-drained mossy meadow, full of timothy grass, was top-dressed during the last week of April, with 1 cwt. of artificial guano, 12 bushels of humus, well mixed with a quantity of ashes. RESULT.—Not so good; more affected by drought; crop 160 stones per acre; the rest of the undressed meadow land, on an average, 140 stones per acre.

3°. Three acres of rye grass hay, upon *a very light sharp soil*, was top-dressed during the last week of April, with 3 cwt. of artificial guano, ½ cwt. of improved bones, 1 cwt. of charcoal, all mixed with a quantity of ashes. RESULT.—I cannot pronounce that the hay on the three acres was increased in bulk; the crop was a light one in the whole field, owing to the severe drought, and the very dry nature of the soil this season, therefore, gave this experiment no fair trial. I would say, however, that I have rarely seen such an appearance of white clover since the hay was cut, and particularly on the dressed land.

B. On *pasture grass.*

Three years' old lea. The extent 2 acres 3 roods Scots measure, divided into three equal parts, and the manures applied during the last week of April.

No. 1. Dressed with ½ cwt. of ammoniacal salts, 1 cwt. of sulphate of soda (glauber salts.)

No. 2. Dressed with ½ cwt. of ammoniacal salts, ½ cwt. of glauber salts, ½ cwt. of common salt.

No. 3. Dressed with ½ cwt. of ammoniacal salts, ½ cwt. of glauber salts, ½ cwt. of nitrate of soda.

RESULTS.—Nos. 1, 2, and 3 were much alike; in all the three cases the vegetation was quickened and improved; but, as is always the case with experiments on pasture, unless the cattle were kept off for the whole season, and the produce cut, it is not easy to say how far the above application went to improve the grass; but certainly the small field did wonders—for it pastured fifteen early calves nearly all the season.

II. The following carefully conducted series of experiments were made by Mr. Fleming, of Barochan, with the view of determining the *relative effect of saline substances upon the weight of the hay crop*, on the field where the experimental wheat of 1841 was grown:—

Result of Experiments tried upon sown Grass, cut for Hay on 30th June, 1842, Crook's Farm, where the Wheat grew in 1841. (See preceding part of this Appendix, p. 26.) *The quantity of land in each plot was one-sixteenth of an imperial acre.*

No.	CROOK'S FARM, BAROCHAN. Description of dressing.	Quantity applied.	Produce in imperial lbs. when cut.	Weight in imperial lbs. when cut, per imperial acre.	Increase per imperial acre in lbs.	Weight when dried, 22d of July.	Quantity of dried Hay yielded by 1000 lbs. fresh cut.	Weight in tons, &c., when cut green, per acre, 30th of June.		
		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	tons.	cwt.	qrs.
	Nothing		710	11,360	—	195	275	5	1	2
1	Sulphate of Soda	21	484	7,740	—	163	337	3	9	0
2	Common Salt	21	672½	10,960	—	176	262	4	17	3
3	Nitrate of Soda	10½	1125	18,100	6640	351	312	8	0	3
4	Sulphate of Soda Nitrate of Soda, mixed,	7 3½	515	8,240	—	166	362	3	13	2
5	Natural Guano	10½	932½	14,920	3560	256½	275	6	13	1
6	Silicate of Potash Gypsum	3½ 21	757½	12,120	760	198	262	5	8	1
7	Sulphate of Ammonia	7	820	13,120	1760	225	275	5	17	0
8	Turnbull's Guano	14	595	9,520	—	186	312	4	5	0
9	Common Salt Soot	14 1 bushel	795	12,720	1360	228	287	5	13	2
10	Hay of Barley Land, manured with bone-dust, 1841,		940	15,840	3680	305	324½	6	14	1

Remarks.—Nos. 1, 2, 3, 4, 5, and 8, were all dressed on the 9th of April, the weather being very dry at the time, and their effects were hardly perceptible; but in the last week of April Nos. 3 and 4 showed an improvement over the others. We had heavy rains the first week of May, and by the 7th of May the nitrate of soda (No. 3) could be seen at a distance by the alteration of the colour to dark green, and its height above the others; upon that day Nos. 1 and 2 showed no visible alteration from the undressed. No. 3 was the best of any: taller, and of a dark green colour, and thicker swarded. *No. 4 showed little or no alteration in colour, but was fully longer than the general crop, and presented the remarkable appearance, as did No.* 1, *in being nearly all* Festuca Rubra, *with hardly any rye-grass, although of this grass, viz.* (Festuca Rubra) *none was sown; the field having been sown with rye grass, timothy and red clover.* No. 5 darker than No. 4 in the colour, and good; but No. 8 hardly improved. Nos. 6, 7, 9, and 10, were dressed upon the 7th of May. The men, in ploughing up the stubble of 1841, found that the ridges which were top-dressed that season with nitrate of soda, were more difficult to plough, from the strength and depth of the grass roots, than the ridges undressed, each alternate ridge only having been dressed.

Prices of Manures.—Sulphate of Soda, 7s. per cwt.; Nitrate of Soda, £1 per cwt.; Natural Guano, 25s. per cwt.; Artificial Guano, 8s. per cwt.; Silicate of Potash or Soluble Glass, 15s. per cwt.; Sulphate of Ammonia, £1 per cwt.

G.—EXPERIMENTS UPON MIXED CROPS.

The following interesting experiment was made by Mr. Alexander, for the purpose of ascertaining *the effect of a mixture of gypsum and common salt upon a mixed crop of oats, beans, and peas* :—

Result of an experiment upon the effect of gypsum and common salt, applied as a top-dressing at Wellwood, Muirkirk, 1842.

Four Scotch acres of strong soil, bordering on clay, broken up from two-year-old pasture, were sown with oats, beans, and peas (which is called in Scotland *mashlem*, and is a first-rate fodder for dairy stock). They all came well up, but worming and other causes injured the crop so much that I had serious intentions of ploughing it up, and sowing turnips. Instead of doing so, I top-dressed the whole four acres with the following substances, well pounded and mixed together, and this being done immediately before copious rains, the mixture was washed into the soil:—12 cwt. gypsum (from Turnbull), which, with carriage, cost 8s.; 4 cwt. common salt, which, with carriage, cost 8s.;—this and the gypsum 16s. Cost of top-dressing, 4s. per acre.

The effect was like magic; the plants immediately assumed a deeper green colour, and grew wonderfully, and this field took the lead of all my other oats, and when reaped the field generally was the best I had. Oats, beans, and peas were all particularly well filled. I may state further, that after the dressing it stood the severe drought better than any of my other crops. Wellwood is 23 miles from the sea, and 550 feet above it.

From other experiments which I had before made, but which I shall not further enter on here, I am convinced that common salt is a great auxiliary in that locality (if not to most others distant from the sea), and it ought to be far more extensively used.

H.—EXPERIMENTS UPON BEANS.

The following experiments were made by Mr. Alexander, of Southbar, at his farm of Wellwood, in Ayrshire, with the view of ascertaining the relative *apparent* effects of different saline top-dressings upon beans *at different periods of their growth* :—

Experiments made at Wellwood upon a crop of *beans* (1842).

The ground was manured, previous to sowing, with 15 tons of farm-yard dung per Scotch acre, and the other manures applied *when the beans were about two inches high* (they were sown in broad-cast). The extent of ground was 2½ acres Scots measure, divided into four equal proportions.

No. 1. Dressed with ¾ cwt. of sulphate of soda, ¼ cwt. of nitrate of soda. Result.—The effect of the dressing was seen soon after application by deepening the colour of the plants. The beans were deficient in straw, but remarkably well podded and filled.

No. 2. Dressed with ½ cwt. of sulphate of soda, 1 cwt. of gypsum. RESULT.—More straw than the foregoing, and rather better crop.

No. 3. Dressed with ¼ cwt. improved bones, ¼ cwt. artificial guano, 3 bushels of Turnbull's humus. RESULT.—About the same as No. 1.

No. 4. At first not dressed; but, in consequence of being weakly, was afterwards top-dressed with 3 cwt. of gypsum, and 1 cwt. of common salt, done in consequence of the highly beneficial effect produced on the four acres of mashlem crop above alluded to. RESULT.—*Though done so late that the beans were already coming into flower, it helped them much*, and they ended as well as any of the above. It may here be remarked, that all the beans were—particularly for that high district—heavy, being on trial soon after mowing 65 to 66 lbs. per bushel.

I. *Observations upon the effect of the top-dressings applied in* 1841 *upon the crop of* 1842.

The following remarks are quite as interesting as any thing contained in the numerous experiments made this year at Barochan by Mr. Fleming's skilful overseer. They are, I believe, the first *systematic series* of observations of the kind yet published. They are valuable, therefore, as the first steps in the line of *prolonged* observations upon the same land made during successive seasons, by which prolonged observations only can we hope to eliminate the effect of our variable seasons, and to arrive at true deductions in regard to the kind and amount of effect which this or that manure is fitted to produce.

I do hope that Mr. Gardiner, who is capable of observing so well, and of experimenting so accurately, will not lose the opportunity which the present year will afford him of continuing these important observations:—

1°. Top-dressings upon hay, Covenlea field (see Appendix, p. 27). On looking over this field at different times, and particularly early last spring, the square on which nitrate of soda and bones mixed had been sown was earlier, and of a darker green colour, than any of the rest of the field, and when stocked with cattle, the portion top-dressed was more relished, and consequently always eaten quite bare.

2°. Upon part of the pleasure-ground—soil a very stiff blue clay—nitrate of soda was sown at the rate of 160 lbs. per acre. After this application white clover came up very thick and strong.

and it was cut three different times with the scythe, and each time it came up stronger and thicker than the surrounding grass, whilst, before dressing, it was the weakest, and this season, 1842, it is better, and the portion dressed still easily distinguished.

3°. The field at Crook's farm (see Appendix, p. 27), which had been top-dressed with nitrate of soda, applied on each alternate ridge, on being ploughed up from hay stubble was found tougher upon the dressed ridges, the grass roots being stronger and deeper in the soil of those ridges which had been dressed.

4°. At p. 34 of this Appendix an experiment upon moss-oats i recorded. This was sown down with a mixture of grass a clover seeds, and cut for hay this season, 1842. In examin the hay crop some of the dressings on the oats of last year seeme to have had a good effect on the hay crop of this year. Nos. and 2 were the worst of any; No. 3 very little better, rath more clover; No. 4 excellent, very thick of red and white c vers and rye-grass, and the hay was of a good quality; No. 5 little better than No. 3, but far from being equal to No. 4; No. the best of any, full of red and white clovers and rye-grass, a had three-fourths more hay upon it than all the others exce No. 4; No. 7 not better than the undressed; Nos. 6 and 4 p sented a most remarkable appearance compared with the othe and any person seeing them, and not knowing the circumstan of the case, would have said that these two portions only been cultivated, while the rest had been left in a state of natu After being cut for hay, the aftermath of these two portions presented the same difference of appearance in the sward, they continue of a better colour.

A. F. GARDINE

GENERAL REMARKS ON THE ABOVE EXPERIMEN OF 1842.

However valuable the above experiments may be, and how interesting the results to which some of them may appear to it is of importance to bear in mind—

1°. That they are the results only of a single season, and t remarkably dry one.

2°. That they show the effect of the substances employe certain localities only—the localities differing in the natu their soil—in their distance from, and height above, the sea—in the average fall of rain to which they are subject.

3°. That the results are obtained by trials upon certain *var* of each crop only, and may not be obtained even on the same

with other varieties—of turnips for example, of potatoes,
wheat, or barley.

4°. And that other causes, not yet noted, may have existe
sufficient influence to prevent the exact results from being
tained upon a repetition of the experiment.

5°. Above all, it must be borne in mind that we are yet in
first infancy of accurate experimental agriculture—that it
take many careful repetitions of our experiments before we
eliminate the effects of the seasons—of the altitude of our fa
their distance from the sea, the falls of rain to which they
subject, and the kind of soil of which they consist. In the n
time our most careful deductions must be considered as *pa*
only, and as *open to doubt*—as facts by the combination and c
parison of which we are hereafter to arrive at more general tru

With these preliminary observations, I turn to the experim
themselves—

A.—*The experiments upon turnips.*

The first series, those of Lord Blantyre—except the gen
answer *that saline substances cannot replace farm-yard manu*
afford no very satisfactory results. They exhibit, indeed, s
striking circumstances—such as

1°. That 100 lbs. of salt per acre may, in a dry season, red
the natural or unaided produce of turnips one-half—and that
same weight of nitrate of soda may reduce it one-fourth.

2°. That in such a season as much as 16 cwt. of rape-dust
acre may be applied, one-half drilled in, and one-half as a t
dressing, *without producing any sensible benefit.*

3°. That the same may be the case, if eight cwt. of rape-dust
drilled in, and half a cwt. of nitrate of soda be afterwards appl
as a top-dressing—while if the same weight of common salt
used as a top-dressing instead, the crop will be increased one-h

These results are too anomalous to be considered for the pres
as more than accidental. They may possibly be explained eit
by the different degrees of moisture of the several parts of t
field in which the mixtures were applied—or on the suppositi
which is very probable, that in the concentrated state *some of th*
saline substances are more hurtful to the growing plant than othe
It is to be regretted that the season was so unpropitious to t
series of experiments, for though the following experiments
Mr. Fleming afford some valuable information, further knowled
still is wanted in regard to the *relative effects of different sali*
substances upon the growth of turnips, where no fermentible manu
is applied.

4°. In these experiments, a striking contrast is presented b tween the effects of rape-dust and those of guano. 16 cwt. per acre of the former gave only 3¾ tons of turnip bulbs, while 2 cwt. per acre of the latter gave 5 tons. It appears, therefore, that *rape-dust requires moist weather or occasional rain, while guano, even in very dry seasons, will produce a considerable effect.* This is consistent with what we know of the employment of the latter substance as a manure on the arid plains of Peru.

II. The next four series of experiments, those of Mr. Fleming, are rich in results and suggestions.

1°. *Limits of error.*—The first observation which a careful examination of them will lead the reader to make—and it appears to me to be a very important one in reference to all future experiments of this kind—is suggested by the second series—those upon *early yellow turnips*, p. 68.

In this series there are included two plots (Nos. 5 and 18), upon which no manure was used. Upon one of these the produce amounted to 12 tons 17 cwt., upon the other to 11 tons 8 cwt. only —being a difference of 1½ tons, or one-eighth of the whole. This difference between two equal portions of the same field, apparently similar in soil, could scarcely, I think, have been anticipated, and it shows that—*where the produce obtained by the application of two unlike manures, to this turnip crop, does not differ more than 1½ tons per acre, the effects of the two manures may be considered as practically equal*—since this amount of difference may have arisen from the unlike qualities of the two plots of land, to which the manures were respectively applied.

This is an important practical rule for enabling us to judge accurately in regard to the true effect of the several manures employed in the series of experiments (p. 68) referred to, but the fact itself suggests also an important modification in the mode of conducting all similar comparative experiments in future.

In my previously published Suggestions, I have recommended the setting apart of *one* undressed portion only of the field on which the trials were made—considering that the produce of this portion would represent the average fertility of the whole undressed part of the field. But these experiments of Mr. Fleming seem to show that this opinion cannot safely be entertained. It appears to be necessary, therefore, in all future experiments from which accurate deductions are intended to be drawn—*that two undressed plots, at least, should, in each case, be measured out, and their relative produce ascertained,* in order to afford a trustworthy average of the unaided fertility of the land.

Suggestion 1.—For the clearing up of this point, however, it would be very desirable to institute a series of weighings of the produce of equal portions of land, in several different parts of the same field, the whole of which has been tilled and manured in the same way. This would throw some certain and satisfactory light upon the amount of variation which, from natural causes, may take place in the same crop, grown upon different parts of the same field, and under the same circumstances. We should thus be enabled to allow for the influence of natural causes upon the results of such experiments as are made, with the view of determining the true action of the different manures we apply.

Suggestion II.—But if some slight difference in the soil, which the eye cannot detect, be capable of materially affecting the natural produce of the unmanured parts of a field, it may also be sufficient to modify—that is to increase, or to lessen—the effects produced by the saline and other manures we apply to the different parts of the same field. It suggests itself, therefore, as the more prudent and wary course of experiment to dress two plots at least with each of the manures whose relative virtues we are desirous of testing, and these in different parts of the piece of land upon which our trials are made. The mean produce of the two or more plots we thus dress, compared with the mean produce of those to which no dressing has been given, will indicate more nearly the average effect of the manure we have been trying, upon the given soil and crop.

The reader will perceive in the new precautions thus indicated, one of those practical results which year by year will necessarily flow from the continuation of the train of inductive experimental research, now, I hope, fairly entered upon by the practical agriculture of our country.

2°. *Guano.*—Among the other experiments upon turnips here stated, those upon guano are the most practically successful. Thus, without any farm-yard manure,

PER ACRE.	PER ACRE. tons.	cwt.		
3 cwt. of guano alone gave	23	8	of *Swedes* - -	(p. 67).
5 cwt. of guano, with 20 bushels of wood-ashes	32	2	of *Early Yellow* -	(p. 68).
5 cwt. of guano alone	32	15	of *White Globes* -	(p. 70).
3½ cwt. do.	20	0	of *Yellow and White mixed*	(p. 70).
3¾ cwt. do.	23	0	of *Purple-topped Yellow* -	(p. 71).

These results are very gratifying, since they seem to show that for the turnip crop this light and portable manure may be substituted with safety for farm-yard dung. But they are more gratifying in connection with the large reduction which has lately taken place in the price of this substance. In none of the cases above mentioned did the quantity applied exceed 5 cwts. per acre. This quantity may now be purchased for three guineas, though when these experiments were undertaken it cost £6 5s.

It is no small matter of congratulation, that this important reduction has been mainly brought about by the expression of scientific opinion, and by the readiness with which various persons, manure manufacturers and others, have put in practice the suggestions contained in the preceding part of this Appendix (p. 38), for the formation of an artificial mixture in imitation of the natural guano. The fear of competition produced its natural effect upon the market, and led the importers of this substance to content themselves with a smaller profit. It is to be hoped that the more extended sale which has followed the reduction, will leave the spirited merchants who first brought it into the country no reason to regret the diminution in price. The benefits which the practical agriculturist derives from one such reduction as this are not all at first sight perceptible. The demand for guano has so greatly lessened the call for rape-dust, that it has also fallen in price from £8 to £5 10s. per ton. Thus ramified and extended are the results of a single chemical investigation—or the publication of a single well-founded scientific opinion.

3°. *Artificial guano.*—In connection with this subject it is important to ascertain to what extent the attempts to manufacture a substitute for the natural guano have been attended with success—in so far as the turnip crop is concerned. The only comparative results which the above experiments present are the following—those upon Swedes being obtained by the use of 3 cwt. of each mixture, those upon the yellow and white turnips by the use of 5 cwt. of each :—

	SWEDES.		EARLY YELLOW.		WHITE GLOBE.	
	tons.	cwts.	tons.	cwts.	tons.	cwts.
1°. Nothing - - -	12	5	12	17	—	—
2°. Natural guano - -	23	8	32	2	32	15
3°. Barochan artificial guano	17	14	24	2	22	10
4°. Turnbull's artificial guano	14	11	21	4	—	—

These results show that, when equal quantities are employed, equal results are not obtained from the natural guano and from the artificial mixtures. It also appears that Mr. Fleming's mixture is much more efficacious than that of Mr. Turnbull. They are made up, with some modifications, after the *recipe* given in the preceding part of this Appendix (p. 38), but are, no doubt, susceptible of improvement. It is, indeed, one of the indirect benefits which will result from the introduction of this foreign manure, that it will stimulate to experiments, by which we shall, no doubt, at last successfully imitate it—and will lead, at the same time, to a more general and thorough understanding of the principles upon which mixed manures ought to be compounded, and of the mode of preparing them with the greatest possible economy. Many crude mixtures may be made at first, by dealers in manure and others, and many instances of want of success may occur, but now that we have *adopted the system of recording results, whether apparently successful or the contrary, there is little fear of our not arriving at satisfactory and economical truths at last.*

Suggestion III.—In experiments made for the purpose of aiding the real advance of scientific agriculture, I would suggest *that no mixture should be used of which the composition is not exactly known*—which, therefore, has not been either made by the experimenter himself or by some dealer upon whose honour perfect reliance is to be placed. The use of the random mixtures now sold under so many different names, however successful they may be in this or in that case, can never lead to the discovery of useful agricultural principles, and, therefore, are unworthy of the attention of the cultivator of *inductive experimental agriculture.*

4°. *Sulphate of ammonia.*—These remarks lead me to notice the effect ascribed in Mr. Fleming's second table (p. 68), to sulphate of ammonia—one cwt. of which nearly doubled the crop. Thus—

	tons.	cwt.
The unmanured soil gave - - - -	12	17
With 1 cwt. of sulphate of ammonia -	24	11

This is exactly equal to the effect produced by 15 cwt. of rape-dust at a cost of £6. 10s. But the sulphate of ammonia here employed was that prepared by the Messrs. Turnbull, of Glasgow—which is not merely sulphate of ammonia, but a *variable and undetermined mixture.* It is prepared from urine, and I believe is contaminated also with a considerable proportion of saline substances artificially added to it. That it contains many substances useful to plants there can be no doubt, and that it may prove a valuable manure is exceedingly probable, but *under its present name* it can only lead to false deductions in experimental agriculture—and the use of it, therefore, in comparative trials such as these we are now discussing ought to be avoided. It is only, as I have already said, from the use of pure substances, mixed in known proportions, that valuable, because undoubted, conclusions can be drawn. It is in vain to attempt to eliminate the effects of diversity of soil and climate, if new causes of diversity are introduced by the very substances with which our experiments are made.

5°. *Bones dissolved in muriatic acid.*—The action of bones is not in general exhausted in a single season. If they are in the state of fine dust, they decompose more quickly and cease to act in a shorter space of time. By dividing them still more minutely, or by solution in acid, it has been thought that their apparent efficacy might be increased. Mr. Fleming, in 1841, made some experi-

[illegible] which seemed to justify this conclusion. In the present tables other results are exhibited, which favour the same opinion. I place together here the results upon potatoes, as well as upon turnips, for the purpose of comparison:—

	Bone-dust.				Bones in muriatic acid.			
	16 cwt.		18 cwt.		3 cwt.		10 cwt.	
	tons.	cwt.	tons.	cwt.	tons.	cwt.	tons.	cwt.
Swede Turnips -	14	17	—	—	—	—	18	11
White Don Potatoes,	—	—	9	15	12	15	—	—

These results, the only ones contained in our tables which can be compared together, are both greatly in favour of the dissolved bones, in so far as the action upon the *first* crop is concerned. It will require longer observation to determine in which form the same weight of bones will produce the more lasting effects, and will be the more economical on the whole.

6°. *Nitrate of soda.*—The effect of 1 cwt. of this salt per acre upon the early yellow turnip is very remarkable (p. 68), having given upwards of 27 tons of bulbs, at a cost of 25s. It is to be regretted that no similar experiment is recorded upon the other varieties of turnip either by Mr. Fleming or by Mr. Alexander. In the text (Lecture XV., p. 52 to p. 62) an abstract of all the published results hitherto obtained by the use of nitrate of soda will be found in a tabulated form.

7°. *Lime.*—An interesting result in Mr. Fleming's first table may hereafter lead to some satisfactory *experimental* determinations of the points considered still doubtful in regard to the form in which, and the time when, lime may be most efficaciously applied, in reference to the culture of particular crops. He caused carbonate of lime and caustic (newly slaked?) lime to be sown in the drills without manure, and the effect upon the crop of Swedes was as follows:—

		tons.	cwt.
Soil unmanured	- - - - - -	12	5
Carbonate of lime, 20 bushels	- - -	16	11
Caustic lime, 50 bushels	- - -	11	8

The immediate effects of lime applied in these two forms was very different—the caustic lime lessened the turnip crop, while the carbonate increased it by 4¼ tons. This effect most probably arose from the lime, in its caustic state, taking from the soil the carbonic and other organic acids from which the roots in the early infancy of the plant would have derived a portion of their nourishment, and thus retarding and stunting their growth. At all events the experiment seems to indicate that lime ought to be in the state of carbonate—the *mild* state—more or less entirely, if it is intended to benefit the crop to which it is immediately applied. When mixed with manure, however, where vegetable matter abounds in the soil, or where the lime is merely harrowed into the surface—in all which cases it will readily become, in a great measure, saturated with carbonic acid—the skilful farmer will understand that the deduction drawn from the preceding experiment will not apply.

8°. *Rape-dust.*—The results exhibited in this year's experiments, generally, are not so favourable to the employment of this substance as was to be expected. The reason, however, is, probably, that which has already been suggested in discussing the results obtained at Lennox Love—that *rape-dust requires a moist soil or occasional showers.* But this itself is an important *probable* deduction. The reader will find a comparative view of the whole of the results with this substance in the text (see Lecture XVII).

9°. *Animal Charcoal.*—The effect of animal charcoal upon Swedes in Mr. Fleming's experiments is only inferior to that of guano. It is certainly deserving of further trials, and especially in comparison with what is called *exhausted* animal charcoal—that which has already been used in the refining of sugar. In France, the latter is said to be preferred to the former, and to be sold by the sugar refiners at a higher price than they pay for it in the recently-prepared state.

10°. *Other mixed manures.*—In regard to other mixed manures, the reader will find much practical information by the study especially of No. 3 of Mr. Fleming's tables, p. 69; and of Nos. 1 and 2 of those of Mr. Alexander, p. 71. These are the more worthy of the attention of the practical man, since Mr. Fleming considers himself justified in remarking as the general result of the experiments in p. 69, *that any of the mixtures used will in his land produce an average crop of turnips at a less expense than farm-yard manure.* This is the kind of result which it ought to be the ambition of every practical man to work out for himself upon his own land.

11°. *Size and weight of bulbs.*—There remains only one other topic in connection with these experiments to which space will permit me at present to advert. In the remarks upon the table inserted in p. 56, it is stated that the turnips on the plots dressed with—

Guano and wood-ashes—*were pre-eminent for size of bulbs.*

Sulphate of ammonia—*large in bulb, but soft, and light in weight.*

Potash and lime, salt and lime, sulphate of magnesia, nitrate of soda—*small in bulb, but firm and solid.*

Bone-dust and the artificial guanos—both containing bones—*the bulbs firm and solid, but not remarkable in size.*

Now upon the solidity of the bulb—other things being equal—

it may be presumed that the relative nourishing properties of different species of turnip will materially depend. The quantity of water which different specimens of the same variety of turnip contain varies from 79 to 91 per cent.—that is, *some turnips of the same species contain only four-fifths, while others contain upwards of nine-tenths of their weight of water.* In other words, the same variety of turnip may contain such unlike quantities of water, that 2 tons grown on one spot may not contain more than 1 ton grown in another. *The weight of bulbs*, therefore, is no safe criterion of the quantity of food raised on different parts of the same field—where the general treatment, or the substances applied to aid the growth, have been different.

Now in the above experiments the guano gave 32 tons of very *large*, the sulphate of ammonia 24 of *soft*, and the nitrate of soda 27 of *small* and *solid* bulbs. It is probable, therefore, that the actual quantity of food raised by the aid of the nitrate of soda was much greater than even by the natural guano. It may also have been that the 14½ tons of solid bulbs given by the sulphate of magnesia—or the 12½ raised from the land without manure at all, may have contained as much nutriment as the 24 tons of *soft* bulbs raised by the sulphate of ammonia.

Suggestion IV.—The bare possibility of such a circumstance as the last shows how little absolute confidence we can place in the numerical results as yet obtained, *considered as evidences of the greater or less amount of food*, which the use of this or that kind of manure will enable us to raise from a given extent of land. It suggests, also, the necessity of a further determination of the relative quantity of water contained in our experimental turnip crops. This will, without difficulty, be effected by selecting three or four turnips of different sizes from each sample—cutting a slice from either side, and one from the middle of each turnip—weighing the whole—drying them, first in the air, afterwards before a gentle fire, and, lastly, in an oven so hot as not to brown white paper or dry flour, and then weighing. The loss being the weight of the water in the turnips will enable the experimenter to determine the relative quantities of food raised upon his different plots, and therefore the relative value of his different applications or methods of culture.

In this suggestion the reader will perceive another of those precautions which the prosecution of our experimental inquiries renders necessary—future years will suggest others—but the increase of trouble will not deter the zealous labourer in this important field—for the more precautions and difficulties multiply, the greater the honour will be to those who by perseverance shall successfully overcome them.

B.—*The Experiments upon Potatoes.*

Nearly all the experiments in the first table of results (p.
were made with mixed manures.

1°. *Guano and rape-dust.*—Among these the effect of gu
is again striking, and upon two of the varieties greatly excee
that of rape-dust. Thus, the produce of the three varieties tri
was—

	Unaided soil.		With 3 cwt. guano.		With 4 cwt. guano.		With 1 ton of rape-dust.	
	tons.	cwt.	tons.	cwt.	tons.	cwt.	tons.	cwt.
White Don	7	7	18	9	—	—	12	6
Red Don	6	15	—	—	11	6	10	0
Connaught Cups	5	15	—	—	13	14	13	0

We are not enabled, by the experiments before us, to compare its effect with that of farm-yard manure.

A curious question suggests itself upon the inspection of the above numbers—one which could scarcely have arisen in our minds, had not differences such as the above presented themselves among the results of our experiments. Nothing is more common than to ask which of several varieties of potato is the more prolific—and a practical man who has made the trial has no difficulty in giving an immediate answer to the question. But the experiments of Mr. Fleming seem to say that *the relative weight of crop yielded by each of two or more varieties of potato, depends upon the way in which you treat or manure them.* With one treatment a variety (A.) with another a variety (B.) will give the heaviest crop. Thus, our three varieties gave with—

	WHITE DON.			RED DON.			CONNAUGHT CUPS.	
	tons.	cwt.		tons.	cwt.		tons.	cwt.
Natural Guano	18	9	-	14	6	-	13	14
Rape-dust -	12	6	-	10	0	-	13	0

Both substances agree in saying that the *white* is considerably more prolific than the *red* Don. But while the guano adds that both *Dons* are more prolific than the *Cups*, the rape-dust pronounces the latter variety to be superior to either of the former. Now it may have happened that in the last case of the three, the rape-dust, from some circumstance not noticed, may have acted better than in the other two cases, and that in this way the discordance may have arisen. Unfortunately, however, there are upon record no other experiments made upon any two of the varieties of potato with other substances used in like proportion—by which this question might have been in some measure solved. But the interesting, and, as it may hereafter prove, important inquiry suggests itself—*what is the order of relative productiveness of the several varieties of the same cultivated plant, when they are severally dressed or manured with this or with that substance?* This question will, no doubt, hereafter lead to extended series of ve refined experimental inquiries, from which not only much kno ledge but much practical benefit may be derived.

Suggestion V.—It may be, for instance, that a given variety potato, turnip, oat, barley, &c., is more valuable as food, m agreeable to the taste, or brings a better price in the market, l by the ordinary modes of culture is the least productive of th generally cultivated It would, then, be not only an interesti but an important economical question to ask—could this vari be rendered more productive by a different mode of treatmen one especially adapted to its own nature? Would the practi man not rejoice to think that such a result could be brought ab by the aid and suggestions of science? Yet this is the result which the refined series of experiments suggested by the quest above proposed may possibly lead.

May I venture to hope that some of my more zealous rea will be induced, during the present or succeeding summer make trials of the relative effects of the same saline or o known substances and mixtures upon different varieties of same crop—of potatoes, turnips, wheat, &c., in circumstan otherwise equal, in some such form as the following:—

Variety A.			Variety B.			Variety C.			Variety D.			Variety	
Substances.			Substances.			Substances.			Substances.			Substanc	
A.	B.	C.	A.	B.	C.	A.	B.	C.	A.	B.	C.	A.	B.

The results, if carefully ascertained, are sure to lead to goo they should not be successful at once in solving the prob above proposed.

3°. *Solidity and size of the potatoes.*—Nothing is said in the servations of Mr. Fleming, or his overseer, in regard to the or solidity of the different varieties of potato, or of the diffe samples of the same variety on which the experiments were m Yet in connection with the remarks I have already offered t these qualities of the turnip, it is proper to add that the p is subject to similar variations in the proportion of water it tains—and, therefore, in the relative amount of nourish capable of being afforded by equal weights of its dif varieties.

Some potatoes contain less than 70, others upwards per cent. of water, so that while 100 tons of one sampl give only 20 tons of nourishment, the same weight of a will give 30 tons, or one-half more. In general such as gr heavy or clay soils, or such as are less ripe, contain the while those which have been planted upon sandy spots, fully ripe, contain the least water. But the effect produ different soils we begin now to see may be produced by di methods of dressing or *medicating* our crops also.

Suggestion VI.—It would be interesting to determine,
fore, by actual experiment, the relative proportions of wate
tained in the produce of the several experimental patc
potato ground upon the same field, when equally ripe, o
dug up on the same day. This would afford us the means
proximating still more closely to the true *economical* action
different manures upon the potato crop. It may turn out
certain cases the increase of produce, as indicated by a g
weight, is only apparent, while the increased amount of food
may in other cases be considerable, though the balance ind
no increase of weight.

Did we know the relative proportions of water i
several samples of the three varieties of potatoe rais
Mr. Fleming by the aid of guano, and of rape-dust, a
compared together, our conclusion in regard to their re
productiveness, when treated by either substance, mig
materially altered. I hope, therefore, that this point als
hereafter arrest the attention of some of our experimentalist

4°. *Permanent effects of saline manures on the future*
ductiveness of the seed.—Recommending to my practical re
a careful consideration of the effects of an admixture of
ashes with the several dressings applied to the turnip and
crop, I pass on to the two following series of experiments
saline manures upon the potatoe crop (pp. 74 & 75). Thes
series are well conceived, and the results very instructive
these results, the one which seems to me the most dese
of the attention of the practical man is contained in a few w
thrust in as it were, among the remarks appended to the tal
p. 74. In the later printed copies I have caused them to b
in italics, with the view of bringing them into notice. If the r
will turn to p. 32 of this Appendix, he will find a remar
experiment recorded, in which, by top-dressing well-ma
potatoes, with a mixture of $\frac{1}{3}$ of nitrade, and $\frac{2}{3}$ of sulpha
soda, the enormous crop of 30 tons an acre was obtained fro
small plot experimented upon. Some of these potatoes were
for seed, and planted alongside of others of the same va
which had not been so dressed, and the result is stated in th
words above referred to—"*These last, under the same treatme*
every respect, did not produce so good a crop by 15 bolls (3$\frac{3}{4}$
per acre."

In so far, therefore, as this experiment is to be relied u
for we must not be hasty in drawing general conclusions—
pears that the benefit to be derived from a skilful treatment
potato plant does not terminate with the greater immediate
we reap, but extends also into future years, improving the
and rendering its after-culture more productive.

Suggestion VII.—This idea is worth pursuing, were it only for the purpose of making out the possible existence of so important a physiological law—how much more when it appears so pregnant with important practical results? But thus it is in all cases, that the prosecution of experimental research, with immediate reference either to purely scientific or to purely practical results, ends in improving and benefitting both abstract science and economical practice.

I am unwilling to follow out or to reason upon this possible law, as if it were really established; but the possibility of its truth appears to throw light upon such a question as this—why the seed must occasionally be changed if large crops are to be continually reaped. One soil may be adapted to give the plant a large supply of this or that substance in which the other soil is comparatively deficient; and it may be possible to medicate our seed-corn, while growing, so as to give it the qualities which at present it can acquire only by a change of soil.

All this, however, can only be determined by experiment, and the intelligent reader will not fail to be struck with the remarkable richness of these first trials, in suggestions for future carefully conducted experimental researches.

5°. *How should saline manures be applied to the potato crop?*—Ought they to be mixed with the manure, or to be applied as a top-dressing? Mr. Flemming's experiments do not *fully* solve this question; because the soil on his two fields was very unlike in quality. Thus with manure alone, the one field produced 12 tons 15 cwt. the other only 8 tons 17 cwt. per acre. A perfectly satisfactory solution of the question can be obtained *only by experiments* with the same substances, upon the same soil, and with the same variety of potato. Yet the experiments now before us add considerably to our knowledge upon this point, and such of them as are capable of being compared together are much in *favour of mixing the saline substances with the manure.* Thus applied in nearly equal proportions by both methods, nitrade of soda, sulphate of magnesia, and sulphate of ammonia, gave the following results:

	FIRST FIELD. Top dressed.		SECOND FIELD. Mixed with manure.	
	tons.	cwt.	tons.	cwt.
Manure alone	12	15	8	17
Nitrade of soda	16	0	12	7
Sulphate of magnesia	13	5	11	7
Sulphate of ammonia	14	10	13	7

The *proportionate* increase, therefore, in these three cases, is greatly in favour of mixing with the manure, but something may depend upon the soil and season; and, therefore, *other* experiments are necessary before we can draw a general conclusion. It may prove that some act better when applied in one way, in the other.

6°. *Sulphate of soda.*—With this substance applied i way, the singular and consistent result was obtained tha per acre caused no alteration whatever in the *weight* of duce upon either of the two on which the trials were m the respective *qualities* of the crops nothing is stated.

7°. *Sulphate with nitrate of soda.*—The above res sulphate of soda alone, is the more remarkable from th effect produced by this and other sulphates when mix nitrade of soda. This year also, the mixture of nitrate phate of soda added one-half (6 tons per acre) to the greater proportionate increase even than in the experi 1841, which gave an increase of 8 tons out of a total pro 30 tons per acre. But this season Mr. Fleming has tri still greater success, a mixture of 1 cwt. each of sul magnesia and nitrate of soda, the produce rising by the this top-dressing to 22½ tons. The relative effects of sulphates would have been more clearly proved had the tions of nitrate of soda applied per acre in the two mixtur the same.

8°. *Nitrates of soda and potash.*—Another interesting fac to those already registered upon the relative efficiency o two saline substances, is presented in page 74. One weight and a half of

Nitrate of soda . . . gave 16 tons.
Nitrate of potash . . . " 18½ tons.

This difference may have been due to accidental causes- 18½ of the one result may have contained no more food t 16 tons of the other; but the multiplication of accurate ments will eventually lead us to the truth. Apparent failu discordant results must not discourage the practical man. cording all trust-worthy results, the light will almost sp ously spring up at last.

9°. *Silicate of potash.*—The results obtained by the this substance, and the remarks appended to them (p. deserving of much attention. In reference to this con and to the silicate of soda, I beg the reader to turn suggestions contained in this Appendix, p. 63.

10°. *Mixed mrnures.*—The mixtures in page 76 will n be imitated, and by those who can obtain them of know position, comparative experiments may be tried with ad both to theory and to practice.

C.—*The experiments upon Barley.*

The true practical value of the experiments upon barley will be shown by placing them in the following form:—

	Increase.	£	s.	d.	Cost per bush.
Nitrate of soda with common salt,	gave 5 bush for	0	17	6	— 3s. 6d.
Sulphate of soda with . . Sulphate of magnesia, . .	" 7½ bush for	0	15	6	— 2s. 1d.
Guano (at 25l.) . . .	" 17 bush for	3	18	0	— 4s. 7d.
Common salt, . . .	" 6 bush. for	0	4	6	— 0s. 9d.
Turnbull's artificial guano, .	" 2 bush. for	1	4	0	— 12s. 0d.

The cheapest application, without doubt, upon this soil, is common salt. At half the above price guano would produce the barley at 2s. 3d. per bushel, and the larger quantity reaped, together with the value of the straw in the preparation of manure, may satisfy many that either guano or the mixture of sulphates may be used with profit. It is a further recommendation of the common salt however, that it produced the heaviest while guano produced the lightest grain.

From the experiment with nitrate of potash no result can fairly be drawn, in consequence of the great drought of the season (see Mr. Gardiner's remarks.)

D.—*The experiments upon Oats.*

1°. *Negative effect of saline manures.*—The first of the two series of experiments above recorded being made at Lennox Love —like those made at the same place upon turnips—derive their principal interest from the illustration they afford of the *negative* effect of saline manures upon the oat crop, under the influence of great heat and drought. I select the more simple and striking cases of diminution. The undressed part of the field produced 54 bushels per acre.

Common salt diminished this produce by	6	bushels.
Nitrate of soda . . .	12¼	—
Sulphate of soda . . .	15½	—
Rape-dust	9	—
Soot	12¼	—

while 2 cwt. of guano raised the produce to 70 bushels, being an increase of 16 bushels.

These results not only confirm the deductions which we have already drawn from the preceding experiments upon potatoes and turnips—that guano will act even in our driest seasons, while rape-dust requires at least occasional rain—but they go further in showing that, like the saline substances, *rape-dust, and even soot, will materially diminish the oat crop if the season be distinguished by remarkable drought.*

2. *Moss oats.*—The experiments upon moss oats (p. 80) are a continuation and extension of those of 1841, with greater attention to accuracy in the determination of the produce. The last column in the table speaks for itself. The general produce of the field being 43 bushels per acre.

	Increase.		Cost per bush.
Sulphate of ammonia . .	gave 9 bushels	. .	2s. 3d.
Sulphate of soda with Nitrate of soda . . .	" 18 bushels	. .	1s. 7d.
Bones in muruatic acid . .	" 18 bushels	. .	1s. 6d.
Silicate of Potash mixed with the above	" 22 bushels	. .	2s. 6d.

In the last two cases the straw, which is usually *imperfect* in oats grown upon the moss land, was strong and healthy. It is obvious, therefore, that all these experiments deserve repetition, though as here set forth, the increase of grain by Nos. 2 and 3 was obtained at the least cost, and, therefore, to the economist, will appear most important.

E.—*The experiments upon Wheat.*

I. *Effect of Drought.*—The first series, those made at Lennox Love, afford interesting illustrations of the effect of great drought in modifying the action of saline manures and of rape dust, upon the wheat crop. The more prominent results are distinctly brought out when thrown into the following form. The produce of the undressed part of the field being 47¾ bushels an acre, this produce was affected by the several substances employed in the following manner:—

			Decrease per Acre.		Increase per Acre.
Common salt . .	1 cwt.	.	1¼ bush.	.	—
Sulphate of soda .	1 cwt.	.	9¼ bush.	.	—
Soot	32 bush.	.	slight.	.	—
Nitrade of soda .	1 cwt.	.	—	.	slight.
Rape dust . .	16 cwt.	.	—	.	3½ bush.
Guano . . .	2 cwt.	.	—	.	½ bush.

Thus, the nitrate of soda and the soot did no harm, though the drought did not permit them to do any good. Common salt slightly, and sulphate of soda largely diminishes the crop of grain —while of these four substances the sulphate was the only one which diminished the yield of straw. Nitrate of soda and soot largely increased it.

On the other hand, guano slightly increased the yield of grain, and rape-dust added 3½ bushels to the natural produce, both also augmenting the weight of the straw by about one-tenth of the whole.

In this case, then, the rape-dust surpassed in beneficial effect the natural guano, though, as we have already seen, it proved [illegible] which seemed to justify this conclusion. In the present tables other results are exhibited, which favour the same opinion. I place together here the results upon potatoes, as well as upon turnips, for the purpose of comparison:—

	Bone-dust.				Bones in muriatic acid.			
	16 cwt.		18 cwt.		3 cwt.		10 cwt.	
	tons.	cwt.	tons.	cwt.	tons.	cwt.	tons.	cwt.
Swede Turnips -	14	17	—	—	—	—	18	11
White Don Potatoes,	—	—	9	15	12	15	—	—

These results, the only ones contained in our tables which can be compared together, are both greatly in favour of the dissolved bones, in so far as the action upon the *first* crop is concerned. It will require longer observation to determine in which form the same weight of bones will produce the more lasting effects, and will be the more economical on the whole.

6°. *Nitrate of soda.*—The effect of 1 cwt. of this salt per acre upon the early yellow turnip is very remarkable (p. 68), having given upwards of 27 tons of bulbs, at a cost of 25s. It is to be regretted that no similar experiment is recorded upon the other varieties of turnip either by Mr. Fleming or by Mr. Alexander. In the text (Lecture XV., p. 52 to p. 62) an abstract of all the published results hitherto obtained by the use of nitrate of soda will be found in a tabulated form.

7°. *Lime.*—An interesting result in Mr. Fleming's first table may hereafter lead to some satisfactory *experimental* determinations of the points considered still doubtful in regard to the form in which, and the time when, lime may be most efficaciously applied, in reference to the culture of particular crops. He caused carbonate of lime and caustic (newly slaked?) lime to be sown in the drills without manure, and the effect upon the crop of Swedes was as follows:—

		tons.	cwt.
Soil unmanured	- - - - - -	12	5
Carbonate of lime,	20 bushels - - - -	16	11
Caustic lime,	50 bushels - - - -	11	8

The immediate effects of lime applied in these two forms was very different—the caustic lime lessened the turnip crop, while the carbonate increased it by 4½ tons. This effect most probably arose from the lime, in its caustic state, taking from the soil the carbonic and other organic acids from which the roots in the early infancy of the plant would have derived a portion of their nourishment, and thus retarding and stunting their growth. At all events the experiment seems to indicate that lime ought to be in the state of carbonate—the *mild* state—more or less entirely, if it is intended to benefit the crop to which it is immediately applied. When mixed with manure, however, where vegetable matter abounds in the soil, or where the lime is merely harrowed into the surface—in all which cases it will readily become, in a great measure, saturated with carbonic acid—the skilful farmer will understand that the deduction drawn from the preceding experiment will not apply.

8°. *Rape-dust.*—The results exhibited in this year's experiments, generally, are not so favourable to the employment of this substance as was to be expected. The reason, however, is, probably, that which has already been suggested in discussing the results obtained at Lennox Love—that *rape-dust requires a moist soil or occasional showers*. But this itself is an important *probable* deduction. The reader will find a comparative view of the whole of the results with this substance in the text (see Lecture XVII).

9°. *Animal Charcoal.*—The effect of animal charcoal upon Swedes in Mr. Fleming's experiments is only inferior to that of guano. It is certainly deserving of further trials, and especially in comparison with what is called *exhausted* animal charcoal—that which has already been used in the refining of sugar. In France, the latter is said to be preferred to the former, and to be sold by the sugar refiners at a higher price than they pay for it in the recently-prepared state.

10°. *Other mixed manures.*—In regard to other mixed manures, the reader will find much practical information by the study especially of No. 3 of Mr. Fleming's tables, p. 69; and of Nos. 1 and 2 of those of Mr. Alexander, p. 71. These are the more worthy of the attention of the practical man, since Mr. Fleming considers himself justified in remarking as the general result of the experiments in p. 69, *that any of the mixtures used will in his land produce an average crop of turnips at a less expense than farm-yard manure.* This is the kind of result which it ought to be the ambition of every practical man to work out for himself upon his own land.

11°. *Size and weight of bulbs.*—There remains only one other topic in connection with these experiments to which space will permit me at present to advert. In the remarks upon the table inserted in p. 56, it is stated that the turnips on the plots dressed with—

Guano and wood-ashes—*were pre-eminent for size of bulbs.*

Sulphate of ammonia—*large in bulb, but soft, and light in weight.*

Potash and lime, salt and lime, sulphate of magnesia, nitrate of soda—*small in bulb, but firm and solid.*

Bone-dust and the artificial guanos—both containing bones—*the bulbs firm and solid, but not remarkable in size.*

Now upon the solidity of the bulb—other things being equal—

results of some other experimenters; but it does not agree with Mr. Fleming's observations upon the wheat of 1841, nor with those of Mr. Burnet for 1842, and therefore cannot yet be considered as a universal consequence of the application of this substance as a top-dressing.

III. The experiments of Mr. Burnet, of Gadgirth, have already been partially detailed in the text (*Lecture* XVI., Part III., p. 92), and their value explained. They are important, chiefly, as showing,

1°. *Economical mixtures.*—That mixtures can be prepared which, upon some soils, surpass guano in efficacy and in economical value, at its former price. The price being now reduced, other experiments are required, yet still the less effect of guano upon the wheat crop is in accordance with the results of Lord Blantyre. A wet season, however, may alter the numerical relation which these results exhibit. It will be observed that here also Turnbull's guano produced no sensible effect.

2° *Effect of soda.*—The efficacy of the salts of soda, whether the sulphate, the nitrate, or common salt, upon Mr. Burnet's land, are also very striking, half a hundred weight per acre of either producing an additional increase of about 10 bushels of grain.

3°. *Yield of flour.*—Into his tabulated results Mr. Burnet has introduced a new element, and as it seems to me an important one in an economical point of view, namely, *the quantity of fine flour yielded by equal weights of the several samples of grain.* The differences presented in this column are very striking. Thus 100 lbs. of the grain reaped from the plot which was

Undressed gave - - - -	76½ lbs.	of fine flour.
Dressed with guano - - - -	63¾ lbs.	—
With sulphate of ammonia - - -	66¼ lbs.	—
With sulphate of ammonia add nitrate of soda	54¾ lbs.	—

It would be interesting to learn from an experienced miller to what extent such differences affect the money value of the grain to the manufacturer of flour.

4°. *Amount of gluten.*—Through the anxiety of Mr. Burnet to draw as much information as possible from his excellent experiments, I am able to present another feature in regard to the action of these saline and other substances upon the *quality* of the produce.

It is known that the quantity of gluten contained in different samples of flour is very unlike, and that the nutritive property of the flour depends, to a certain extent, upon this quantity of gluten. It has also been stated, as the result of experiment, that the grain which is raised by means of manure containing the largest quantity of nitrogen is also the richest in gluten. With a view to these questions, Mr. Burnet transmitted to me a pound of each of the samples of flour, (see Appendix, p. 8), and upon examination I found them to contain the following proportions of gluten :—

		Water per cent.	Gluten per cent.
No. 1.	No application	16·3	9·4
2.	Guano and wood-ashes	16·15	9·3
3.	Artificial guano and do.	16·8	9·6
4.	Sulphate of ammonia and do.	16·4	10 5
5.	Do. do. and sulphate of soda	15·7	9 7
6.	Do. do. and common salt	15·7	9·6
7.	Do. do. and nitrate of soda	16·4	10·0
8.	Turnbull's guano, gypsum, and wood ashes	15·2	9·1

These results are not without their interest, for though they do not show any *striking* difference in the per-centage of gluten, yet upon the whole the result is in favour of those samples to which the sulphate of ammonia* had been applied. One of these, No. 4, exceeded the undressed grain by about one per cent., or one-ninth of the whole gluten it contained. Were the amount of this gluten *alone* therefore to determine the feeding quality of the grain, this sample might be considered as considerably the most nutritious. But besides the relative proportions of fine flour which they severally yielded, there are other important considerations which bear upon this question, and must influence our judgment. These considerations it would be out of place to present among the present observations. They will be found stated in the text of the Lectures, when in Part IV. we come to treat of the composition of wheat and other varieties of grain—and of their respective values in the feeding of man and other animals.

F.—*The experiments upon Grass.*

I. The experiments of Mr. Alexander are not very remarkable or conclusive. The meadow, which was drained moss full of timothy grass, gave naturally 1 ton 4 cwt. of hay, whereas the one dressing raised the produce to 1 ton 8 cwt., the other to 1 ton 11 cwt., per *imperial* acre. The cost is not stated.

II. But those of Mr. Fleming are very interesting. By referring to page 26, of this Appendix, it will be seen that in 1841 Mr. Fleming obtained a greatly increased produce of hay by the use of nitrate of soda. He informs me that in making the present experiments he was desirous of again testing the efficacy of this salt upon grass, on *the same kind of land*, and of comparing it with that produced by other saline substances. He selected also a portion of the same field, on another part of which the trials upon wheat had been made in 1841 (see Appendix, p. 30), with the view of ascertaining if any analogy could be traced or difference detected, *between their action in* 1841 *upon wheat, and their effect in* 1842 *on sown grasses*—rye-grass, timothy, and red clover. Both objects have been in some measure attained. I shall first present a summary of the results.

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* It will be borne in mind that this is Turnbull's sulphate of ammonia, already adverted to in page 93 of this Appendix.

	OF HAY		Increase.		Decrease.	
	tons.	cwt.	tons.	cwt.	tons.	cwt.
The undressed soil produced	1	8	—	—	0	5
Sulphate of soda, 3 cwt.	1	3	—	—	—	—
Nitrate of soda, 1½ cwt.	2	10	1	2	—	—
Sulphate of soda, 1 cwt. Nitrate of soda, ½ cwt.	1	7	—	—	0	1
Common salt, 3 cwt.	1	6	—	—	0	2
Common salt, 2 cwt. Soot, 16 bush.	1	12	0	4	—	—
Sulphate of ammonia, 1 cwt.	1	13	0	5	—	—
Guano, 1½ cwt.	1	18	0	10	—	—

A mixture of silicate of potash with gypsum produced no sensible effect, neither did Turnbull's artificial guano.

1°. In this repetition of his experiment, therefore, the nitrate of soda on similar land again increased greatly the produce of hay—giving, at the first cutting, an excess of upwards of 1 ton, at a cost of 30s.

2°. But on comparing this action of the nitrate upon grass with its action in the same field the previous year upon wheat—we find that though it considerably increased the crop of wheat, yet every additional bushel raised cost 12s. 6d. as the price of the nitrate added to the land (Appendix, p. 31). It appears, therefore, that *upon soils where the nitrate will not pay when applied to wheat it may yet pay well when applied to grass.*

3°. Again, we find above that 3 cwt. of common salt lessened in a slight degree the crop of hay, while, in 1841, 1½ cwt. increased considerably the produce of wheat, in the same field—the additional grain reaped from the salted portion costing only 6d. a bushel (p. 31). It would appear, therefore, that *on soils where common salt can be profitably used upon wheat it may do injury upon hay.* The only circumstance that renders this deduction less safe is, that 3 cwt. of salt per acre were applied to the grass, which may have been too much considering the dryness of the season.

4°. The latter remark applies also to the sulphate of soda which was laid on at the rate of 3 cwt. per acre. A less addition might possibly have aided the crop. Yet the negative influence of this salt seems great, since 1½ cwt. of nitrate—itself tending to increase the crop—was unable entirely to overcome the diminishing influence of 1 cwt. of sulphate.

But the reason of this apparent inefficiency of the nitrate, when mixed with the sulphate, is in some measure explained by the remarkable fact that *on both of the patches to which the sulphate of soda was applied—the grass that came up consisted almost entirely of red fescue* (Festuca Rubra), *though rye grass, timothy, and red clover, were the only grasses sown.* The sulphate, therefore, must first have checked or entirely destroyed the grasses which had already sprung up, and then have incited the dormant seeds of fescue to germinate, before the fertilizing agency of the nitrate could come into play.

This effect of the sulphate, should it be confirmed by later experiments, will establish the important theoretical principle, that those substances which, when present in the soil, will destroy some of our cultivated grasses, will encourage the growth of others; and the no less important practical truth, that saline substances exercise such a special action on the several crops we grow, that we may hope to discover the means of *aiding the growth of the one or the other at pleasure*, and it may be at little cost.

Suggestion IX.—It is to be recollected that in the case of Mr. Fleming's field it may have accidentally happened that the seeds of the fescue particularly abounded in those plots to which the sulphate was applied. With every disposition, therefore, to advance as rapidly as we possibly can, I think it better to suspend our judgment upon this point, until the following two series of experiments shall have been made in two or three different localities:—

a. By top-dressing any of the ordinary grasses sown—excluding the fescues—on four or more plots, with ½ cwt., 1 cwt., 2 cwt., and 3 cwt. of sulphate of soda respectively, and marking the kind of grasses that most abundantly spring.

b. By sowing half an acre of one or more of the fescues, and especially the *Rubra*, and noting the effect of the sulphate applied in similar proportions upon as many patches as before.

These experiments, it is obvious, would be rendered more interesting were nitrate of soda, alone and mixed with the sulphate, tried on other plots, and on both varieties of grass. I trust Mr. Fleming, whose educated eye enabled him to detect the interesting fact in question, may be induced himself to prosecute the subject by further experiments.

5°. *Suggestion X.*—We have already seen in the above joint action of the nitrate and sulphate, another illustration of the kind of struggle we may suppose to go on between substances tending respectively, the one to increase, the other to diminish the produce. In the joint action of the common salt and the soot when applied together, we have a further instance of the same kind—an increase of 4 cwt. only being caused by the application of 16 bushels of soot, when counteracted by an admixture of 2 cwt. of common salt. Applied alone the increase of produce would probably have been greater. Will any one undertake experiments with a view of further bringing out this interesting mutually-counteracting influence of different applications?

6°. I can only call attention to the large yield of hay naturally obtained from that part of the field on which barley dressed with bone-dust in 1841 had previously grown: Mr. Fleming informs me that no sensible difference in the produce of hay was observed between the undressed part of the field and that upon which the *dressed* wheat had grown in 1841, though the crop was not set apart or weighed, as we might wish it to have been.

III. Since the preceding experiments went to press, I have received the following short notice of trials upon hay made by Mr. Campbell, of Islay:

"It is very difficult to get the tenants in our wild part of the world to expend money in the purchase of foreign substances, however beneficial; and for this reason I have been induced to try the substances mentioned below, because, with the exception of sulphuric acid, the others are to be got in abundance in the island—the pigeons' dung may be got in large quantities in the caves, sea-ware on the shore, and lime is abundant and excellent in quality. The experiment was made thus:—

1. Nothing.		2. Pigeon Dung.		3. Sea-ware, Lime, and Sulphuric Acid.		4. Lime and Sulphate Acid.	
Weight in lbs.		Weight in lbs.		Weight in lbs.		Weight in lbs.	
Fresh cut.	Dry.	Fresh cut.	Dry.	Fresh cut.	Dry.	Fresh cut.	Dry.
240	199	318	275	306	269	293	256

1. A field of about ten acres lately improved from heather, was chosen; the field was well drained and deep ploughed, so as to raise the subsoil (red loam) with the moss. On its surface the grass was sown down with oats—8 cwt. of each substance was used to the acre. Eighty yards square were carefully measured from the centre of each variety, and weighed the day they were cut, and again on the day they were put into stack. The hay was fully ripe when cut.

2. The pigeon dung, which looks like peat-dust, was laid on exactly as it was taken from the cave.

3. One ton of lime-shells was mixed with 12 tons of fresh sea-

ware; after being twice turned the whole of the sea-ware was consumed, leaving only small black particles mixed with the lime: the bulk was reduced to five large carts (not weighed); 4 galls. sulphuric acid, mixed with 400 galls. of water, were added to the powder—a violent fermentation took place, and the bulk was further reduced about an eighth.

4. A ton of lime-shells was prepared according to your recommendation—slaking the lime with the dilute acid.

N.B. One measure of this lime in shells gives three and a half in powder."

G.—*The experiments upon Mixed Crops.*

Mr. Alexander's experiments upon a field of mixed oats, beans, and peas, is very deserving of notice, and will, I have no doubt, be repeated. Not only did the mixture of gypsum and common salt *increase* the ultimate produce—but, as Mr. Alexander says, *it acted like magic*—imparting life and vigour to an apparently dying and worthless crop.

H.—*The experiments upon Beans.*

I. The principal fact of importance in the experiments of Mr. Alexander is, the effect he found his mixture of gypsum and common salt to produce upon the beans *even when already in flower*. This is another of those new and practically valuable observations which, year to year, are sure to present themselves to our observing experimenters as their inductive researches are continued.

II. I am happy in being able to introduce here, though it reached me too late for insertion among the other tables, the following digest of results upon beans, obtained upon Lord Blantyre's farm at Lennox Love. The object of them was to ascertain *the relative effect of certain saline manures, and of rape-dust, and guano, upon beans, after a crop of oats.*

Experiments upon Beans, after a crop of Oats. *The quantity of land in each plot was one-eighth of an imperial acre.* **Seeds sown 25th Feb.; manures applied 13th May; crop cut 8th Aug.; stacked 1st Sept., 1842; and thrashed 6th Feb., 1843.**

No.	FORDHILL FIELD, LENNOX LOVE. Description of Dressing.	MANURES. Quantity.	MANURES. Cost.	Gross weight of produce.	Weight from Thrashing Mill. Grain. Beans.	Weight from Thrashing Mill. Grain. Peas.	Weight from Thrashing Mill. Total.	Weight from Thrashing Mill. Straw.	Weight from Thrashing Mill. Chaff, &c., unweighed.	Weight of beans per bushel.	Quantity of beans in each plot.	Increase of produce in grain. Beans.	Increase of produce in grain. Peas.	Decrease of produce in grain. Beans.	Decrease of produce in grain. Peas.
		lbs.	s. d.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	bushels.	bush.	lbs.	bush.	lbs.
1	Common Salt, ...	14	0 4	588	231	54	285	225	78	65½	3·538	—	—	182	31
2	Common Salt, ... Rape-dust, ...	7 112	7 0	630	265	53	318	230	82	66¼	4·000	·282	—	—	32
3	Nitrate of Soda, ...	14	3 1	672	276	63	339	254	79	66¾	4·134	·414	—	—	22
4	Nitrate of Soda, ... Rape-dust, ...	7 112	8 7	644	280	59	339	253	52	66½	4·210	·490	—	—	26
5	Nitrate of Soda, ... Sulphate of Soda, ...	7 7	2 0	686	282	60	342	258	80	66¼	4·256	·536	—	—	25
6	Sulphate of Soda, ...	14	1 0	700	282	73	355	261	84	66½	4·240	·520	—	—	12
7	Sulphate of Soda, ... Rape-dust, ...	7 112	7 5	700	289	65	354	261	85	67	4·313	·593	—	—	20
8	Rape-dust, ...	224	14 0	700	292	61	353	260	87	66¾	4·374	·654	—	—	24
9	Guano, ...	28	5 0	728	280	68	348	263	117	66½	4·210	·490	—	—	17
10	Nothing, ...	—	—	672	248	85	333	265	74	66¾	3·720	—	—	—	—
11	Soot, ...	4 bush.	4 0	686	234	87	321	281	84	66	3·545	—	—	175	—

Remarks.—The soil of Fordhill, on which they grow, is light and of inferior quality—the subsoil is of indurated clay, interspersed with boulders and small stones, and occasionally beds of gravel. The field was drained every furrow previous to its being broken up from old lea in the winter of 1840—ploughed deep and subsoiled in the Autumn of 1841, and manured with farm-yard dung in the drill before sowing the beans in spring, 1842. Owing to the dryness of the season, the beans were rather short in the straw; the specific manures were applied after the plants had attained some inches in height. *The sulphate of soda* (dry, *not in crystals*) *blackened and destroyed the under-leaves wherever it came in contact with them, but fresh shoots soon appeared, and it did not seem permanently to injure or retard the growth of the plants.* They did not, after the application, show any marked change of colour; and at no period did they seem to differ much from the rest of the field. A few peas were sown among the beans; and in dressing the grain an attempt, partially successful, was made to separate them—each experiment underwent the same process in the dressing. Grain column 1st represents the produce in beans—grain column 2d represents that in peas. The separation, however, not being completely effected, there were left peas among the beans, and some of the smaller and inferior beans among the peas. I thought a distinction of this kind worth making in the Tables, as I observed that some of the lots contained much more peas than others, and conceived that the relative value of the manures, as applied to *either*, might thereby in some measure be shown, as well as their effects on the beans alone more truly exhibited. The gross weights were taken, as those of the other experiments, at the town of Haddington's weighing machine, before thrashing—the detailed weights and measurements by myself.

Wm. Goodlet.

The produce of the undressed part amounted in the above experiment to 29½ bushels, and it is remarkable—

1°. That the soot alone caused a sensible diminution of the gross produce, and alone did not lessen the proportion of peas.

2°. Although the season was so dry the sulphate of soda gave a larger increase than was obtained by the addition of twice its own weight of guano.

3°. That an admixture of half its weight of nitrate with the sulphate of soda did not increase the produce beyond that of an equal weight of sulphate alone. This is different from the action of the latter salt in the case of the other grain crops and of potatoes.

4°. That 1 cwt. of sulphate of soda produce as great an effect as 16 cwt. of rape-dust—the quantity of grain reaped from both applications being very nearly the same.

Suggestion XI.—These striking effects of the sulphate ultimately took place, although when first applied to the young plants it burned and blackened their leaves. I trust that these results will also be tested by repetitions in other years—less droughty, it is to be hoped—and in other parts of the country. For the sulphate of soda Mr. Alexander's experiment seems to say that gypsum, which is still cheaper, may be economically substituted.

5°. It will be seen that guano upon this crop, as upon the wheat already noticed (p. 103), was less successful than some of the other substances employed.

Conclusion.—Upon the observations of Mr. Gardiner in regard to the effect of the dressings of 1841 upon the crop of 1842, I have nothing to add to the remarks I have already made (p. 87) upon thier importance, and upon the good that must follow from continuing them. But in concluding these observations, the reader will please to recollect that I have adverted to those points only, in the above tables of results, which appeared to myself most important. There are many other points to which by a careful study of the table his attention will naturally be drawn. He will consider the observations themselves also, as only so many gropings after truth. The present state of our experimental inquiries can scarcely be supposed as yet to give us more than a glimpse here and there of the true light. Like a man who finds himself in a dark dungeon, we are peering through the comparative gloom of our prison house in the hope of finding some mode of escape into the upper day. Like him we may be long in discovering the true outlet, and the passage upwards may be narrow and intricate;—but the same conviction which will give him safety, will ultimately lead us also to the light—that he who persists in trying—marking and recollecting every turning he has explored—*may* at length escape; but that he who sits still, in indifference, or gives up his quest in despair, is *sure* to die in the darkness.

No. IX.

ADDITIONAL EXPERIMENTS IN PRACTICAL AGRICULTURE, MADE IN 1842.

The following experiments were made at Erskine, in Renfrewshire upon the Home Farm of Lord Blantyre:—

EXPERIMENT I.—*Potato Oats, after old grass.*

The soil was variable, chiefly good loam, resting on a subsoil partly gravel and partly sand. The field, having been long in pasture, in many places very wet, was drained in November and December, 1841; ploughed soon after, and sown with oats on the 8th of April. The manures were applied on the 15th of April, and harrowed in with a single stroke of the harrows. *One-fourth of an imperial acre being previously measured off for each plot.*

According to notes taken of the appearance of the crop from time to time—

May 23.—The nitrate of soda (No. 1) looking darker in colour than any of the other plots; next to it, in point of colour, the foreign guano (No. 5) seems best; then the soot (No. 9); then the sulphate of ammonia (No. 2); cannot, however, discern any very decided difference in the appearance of the others.

May 30.—There appears a slight difference in favour of all the applications in the order above stated, the sulphate of soda (No. 3) pale in colour.

June 28.—Appearance same as on 30th May.

The crop was cut 19th and 20th of August and thrashed from the stook on the 7th of September; the results carefully ascertained, the grain by weight and measure; the straw by weight, as it came from the thrashing-machine; no account taken of the chaff.

RESULTS OF EXPERIMENT I.—OATS.

No.	Applications.	Cost of application on ¼ of an acre.		PRODUCE.						Increase + or Decrease —	
				Good Grain.			Light Grain		Straw.		
				bush.	lbs.	Weight p. bush.	lbs.	W'ght. p. bush.		Grain	Str.
		s.	d.			lbs.		lbs.	lbs.	lbs.	lbs.
1	Nitrate of Soda, 28 lbs. . .	6	3	12	21	42½	8	28½	908	+28½	+191
2	Sulphate of Ammonia, 28 lbs.	5	0	12	22	40	10	—	770	—	+ 5
3	Sulphate of Soda, 56 lbs. . .	3	0	12	—	40	14½	—	762	— 18	+ 4
4	Nothing . . .	—	—	12	16	44	10½	—	717	—	—
5	Foreign Guano, 28 lbs.	6	3	12	4	44	6½	—	769	+ 6	+ 5
6	Turnbull's British Guano, 56 lbs	4	0	12	17½	41½	10½	—	788	+ 14	+ 7
7	Turnbull's Improved Bones 56 lbs. . . .	3	0	11	2	41	10½	—	675	— [illegible]	— 4
8	Turnbull's Humus, 10 bush.	10	0	11	9½	41	11½	—	644	— 41	— 7
9	Soot, 10 bush. . . .	2	11	13	30½	41	9½	—	880	+ 60	+16

EXPERIMENT II.—*On Old Pasture Grass to be cut for Hay.*

The soil was of medium quality, on stony clay subsoil. The part of the field experimented on was originally very wet, producing scarcely any better herbage than rushes and other semi-aquatic plants, was drained in 1835, has been three years pastured after a crop of hay from young grass in 1838; the soil is of a blackish friable texture, the subsoil very retentive. The specific manures were applied on 15th April, with the exception of the soot, which was sown on the plot in the experiment at the same time that the other parts of the field were dressed with soot, being about the middle of March, and by the 15th of April were showing a greener shade than the portion left for experiment.

April 25.—Observed the ridge or plot No. 5 (sulphate of ammonia) looking dark in the shade, and that the salt has burned the leaves of daisies and other broad leaved plants; the moss or fog seems also to be burned, it looks black and unhealthy.

May 7.—The ridges or plots No. 2, 5, and 7, looking decidedly better than the rest; No. 3 also seems farther advanced than where no applications were made.

May 23.—No. 2 getting on very fast, and now looks as well as No. 1, which has always had the advantage (to appearance) of the other plots. The grass on No. 3 pale in colour, but taller than where no manure was applied.

The hay was cut on the 3rd of July, and the grass weighed soon, *i. e.*, in a few hours after being cut down, but being very sunny weather it was somewhat faded when weighed. The made hay weighed and put into stack on

Each plot consisted of one-fourth of an imperial acre.

RESULTS OF EXPERIMENT II.—HAY.

No.	Applications.	Cost of application.		PRODUCE.		Increase in Hay.
				Grass.	Hay.	
		s.	d.	lbs.	lbs.	lbs.
1	Soot, ... 10 bushels	2	11	2331	970	188
2	Nitrate of Soda, ... 40 lbs.	8	11½	2536½	1026½	244½
3	Sulphate of Soda, ... 80 lbs.	4	3½	1936	841	59½
4	Nothing, ...	—		1760	726	—
5	Sulphate of Ammonia, .. 40 lbs.	7	1½	2516½	935	153
6	Nothing, ...	—		2374	838	—
7	Foreign Guano, ... 40 lbs.	8	11½	3024	1190	408
8	Turnbull's Brit. Guano, 80 lbs.	5	8½	2841	1044	262

N. B. I take the average of the two plots which had no manure, as the sum to deduct for finding the increased produce. The second column from the right is made hay, the third is green grass, weighed soon after being cut.

EXPERIMENT III.—*Upon Wheat.*

Soil—a good strong loam, resting on a heavy subsoil composed of clay and small stones, called till. The wheat was sown in November, 1841, after a crop of potatoes. The field had been long in grass previous to 1840—when it was drained, and ploughed for oats in the spring of 1840—was well dunged with farm-yard manure, and was also limed for the potato crop of 1841, so that the field was in very good condition for wheat.

The manures were applied 14th April, 1842, and harrowed in with a stroke of the harrows.

May 10.—The portion No. 1 seems darker in shade than No. 9 and No. 8.

June 28.—A calm day, with gentle rain—many of the lots much bent down, as follows:—No. 1 much bent down. No. 2 partly swirled and bent at the end next a planting. No. 3 swayed at east end next the planting, not so bad as No. 2. No. 4 less bent down than No. 3. No. 5 much bent down and swirled. Nos. 6 and 7 all standing. No. 8 partly laid down. No. 9 very much swirled and laid. All the laid wheat came up again a few days after the rain.

The wheat was reaped with the sickle, and in due course stacked, in good condition. It was thrashed on the 8th February, 1843.

RESULTS OF EXPERIMENT III.—WHEAT.

No.	Applications.	STRAW.		GRAIN.		
		Total quantity.	Increase + or Decrease —.	Total quantity.	Weight per bushel.	Increase.
		lbs.	lbs.	bush. lbs.	lbs.	bush. lbs.
1	Soot, 10 bushels........	1213	+ 205	13 33	58	2 32
2	Turnbull's Humus, 10 bus.	1055	+ 47	12 48	60	1 47
3	Improved Bones.......	973	— 35	11 58	62	0 57
4	Turnbull's British Guano	1193	+ 185	14 43	61	3 42*
5	Foreign Guano.........	1049	+ 41	11 34½	61½	0 33½
6	Nothing.............	1008	——	11 1	62	——
7	Sulphate of Soda......	1073	+ 65	13 7	62	2 6
8	Sulphate of Ammonia...	1138	+ 130	13 38	62	2 37
9	Nitrate of Soda........	1159	+ 151	13 38	62	2 37

EXPERIMENT IV.—*On Potatoes.*

Soil—a medium loam, resting on gravel and sand. The field was ploughed from old grass, and sown with oats in 1841; was drained (where wet) and deep ploughed in the Autumn of 1841; prepared for potatoes in the Spring of 1842, and well dunged at the rate of about 45 tons of very good dung from Glasgow, per acre. The manures were applied in addition to the dung, by *being sprinkled above the dung in the drills, before placing the sets*, then covered by reversing the drills, on the 21st and 22d of April, 1842.

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* I can ill reconcile the great produce from No. 4 with the appearances when growing, and have been suspicious, that notwithstanding every precaution being taken to avoid mixing, some sheaves of No. 5 plot, have been

During the season could discover little or no difference in the appearance of the portions dressed with the specific manures, from where no applications were made, the crop was a very equal good one over all the field. *One-fourth of an imperial acre in each plot.*

RESULTS OF EXPERIMENT IV.—ON POTATOES.

No.	Manures.	Cost.		Produce.				Increase + or Decrease —.		
		s.	d.	tons.	cwt.	qrs.	lbs.	cwt.	qrs.	lbs.
1	Nitrate of Soda, 14 lbs Sulphate of Soda, 28 lbs.	4	7½	3	0	1	24½	+ 1	1	17½
2	Sulphate of Soda, 28 lbs. Sulphate of Ammon. 14 lbs.	4	0	2	19	0	24½	+ 0	0	17½
3	Foreign Guano, 28 lbs.	6	3	3	0	0	0	+0	3	21
4	Turnbull's Brit. Gua. 56 lbs.	4	0	2	19	2	21	+0	2	14
5	Soot, 7½ bushels, . . .	2	6½	2	15	3	21	—3	0	14
6	Improved Bones, Turnbull's 56 lbs.	3	0	2	19	2	21	+0	2	14
7	Gypsum, 1 bushel, . .	—	—	2	18	1	21	—0	2	14
8	Nothing, ...	—	—	2	19	0	7	—	—	—

The gypsum used turned out not to be genuine on analysis.*

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taken to No. 4, while the crop was in stook, as it was sometimes necessary (during the time the stooks were in the field) to have them repaired, they being blown down once or twice.

The cost of the applications, as also the quantities applied, of the different manures, were the same as in Experiment No. I., on Oats. The light grain is not here taken into account, as it was too trifling in quantity and quality to be of any importance, and nearly the same in every case.

* List of prices paid for the manures used in the foregoing experiments:—

1.	Foreign Guano - - - - - - - - - - -	25s. per cwt.
2.	Turnbull's Guano - - - - - - - - - -	8s. " "
3.	Turnbull's Improved Bones - - - - - -	6s. " "
4.	Turnbull's Humus - - - - - - - - - -	1s. per bushel.
5.	Nitrate of Soda - - - - - - - - - - -	25s. per cwt.
6.	Sulphate of Soda (dry) - - - - - - - -	6s. " "
7.	Sulphate of Ammonia - - - - - - -	20s. " "
8.	Soot - - - - - - - - - - - - - - -	3½d. per bushel.

Nos. 2, 3, 4, and 7, were manufactured and furnished by Turnbull and

REMARKS UPON THE PRECEDING EXPERIMENTS.

1°. *Effect of the drought.*—It is to be observed, in the first place, that the great drought of the season exercised an unfavourable influence upon the result of these experiments also. It is necessary, therefore, to suspend our judgments in some measure regarding them—until future experiments in other seasons shall confirm or modify them.

2°. *Inferences to be drawn from the colour of the crop.*—A new feature introduced by Mr. Wilson in the account of these experiments is, the appearance presented by the several crops at different specified periods after the dressings were applied.

It is a common thing for practical men to estimate the relative produce of different fields or parts of the same field by their appearance, and especially by the colour of the growing crops. Yet that this is not to be depended upon in *a corn* crop is proved by the observation that up to the end of June appearances in the oat field were most in favour of the nitrate of soda, the guano being second and the soot third in order. Yet when reaped, the

Nitrate gave an increase of only .	2 bushels per acre.
Guano	24 lbs. per acre.
Soot	6 bushels per acre.

The nitrate did give a little more straw than either of the other two, but that the colour is not an unfailing criterion even as to the produce of straw or of hay is shown by the experiments upon oats and upon hay. In both of these crops the portions dressed with sulphate of soda are described as *pale in colour*, and yet the excess of produce over the undressed part was as follows :—

	Excess.	
In the oats - -	1½ cwt. straw.	Where the Sulphate was applied.
In the hay -	2 cwt. per acre.	

The increase in neither case would be deserving of much atten-

Company, Chemists, Glasgow. The British Guano, (No. 2) is said to be made up as follows :—

2 cwt. of Sulphate of Soda.
2 cwt. of Sulphate of Ammonia.
1 cwt. of Common Carbonate of Soda.
15 cwt. of Improved Bones, manufactured by Turnbull & Co.

20 cwt., or 1 ton.

The Improved Bones are said to be half dissolved bones, and half wood-charcoal. I believe the bones include animal matter, as I am informed the carcasses of old horses, &c., are all used in the manufacture.

JAMES WILSON.

Freeland Erskine, 20th February, 1843.

tion—except as showing satisfactorily that wrong conclusions may be drawn in regard to the efficacy of manures and top-dressings by those who judge only by the eye—and that *safe reliance can be placed on those comparative results only which have been tested by weight and measure.* I know, indeed, that practical farmers who have applied nitrate of soda to grass land, and have been delighted by the beautiful green colour which followed—have occasionally been disappointed by finding that after all this promise the weight of hay obtained was no greater than upon the undressed parts of their fields. As to the feeding qualities of the two kinds of hay no experiments have yet been made, though it is known that cattle prefer that which has been dressed.

Suggestion XI.—I put down therefore, as a distinct suggestion for the purpose of drawing attention to the subject—that this plan of *specially* noting the appearance of the crops at *stated*, say monthly periods, should be adopted in all future experiments. This will serve, not merely to show more clearly what kind of appearances are to be trusted, and how far, as indications of an increase of crop—but may hereafter prove of further importance when experiments shall begin to be instituted upon the feeding properties of crops reaped under different circumstances, and raised under different kinds of management.

3°. *Importance of having two or more experimental plots similarly treated.*—The experiments upon hay above-mentioned exhibit another illustration of the fact adverted to in page 89 of this Appendix under the head of *limits of error*. I there drew the attention of experimenters to the difference in the produce obtained on two equal patches of the same field of turnips, to neither of which any dressing had been applied. At Erskine two equal plots of grass in the same field gave a similar difference of produce. I present both results here for the sake of clearness. The produce, *per imperial acre*, was—

	Hay at Erskine.		Turnips at Barochan.	
	tons.	cwt.	tons.	cwt.
1st plot	4	5	12	17
2nd plot	3	3	11	8
Difference	1	2	1	9

In my remarks upon the difference between the two plots of turnips (Appendix, p. 89), I expressed an opinion that differences equally great, depending not at all upon the substance applied, might be expected on equal portions of those fields upon which our different saline manures may have been applied;—and that very erroneous conclusions might thence be drawn in regard to the absolute and comparative effects of the substances with which our experiments are made upon the crops to which they are applied.

I have since met with a confirmation of this view in a record of two pairs of experiments made with equal quantities of rape cake upon equal plots of red wheat, in the same season, and upon adjoining parts of the same field.* The results of two experiments with different quantities of rape-dust were as follows :—

	Rape-dust applied. stones.		Produce of market corn. bush.		Weight per bushel. lbs.	oz.		Light corn. lbs.
1st plot . . .	59½	. .	26	. .	52	10	. .	45
2nd plot . .	do.	. .	21	. .	50	8	. .	67
1st plot . . .	86	. .	28	. .	53	4	. .	35
2nd plot . .	do.	. .	22	. .	51	2	. .	91

The differences both in the quantity and in the weight of the grain reaped, in each of these pairs of experiments, are so great that had they been obtained from plots of ground dressed with different manures, we should readily have ascribed them to the unlike action of the substances we had applied. Doubts may naturally arise, therefore, when we look at the several tables of results contained in this Appendix, how far the differences presented in them are really due to the unlike action of the manures employed, and how far to natural causes not hitherto investigated. Can all the experiments made during these last two years with so much care really be vitiated by this source of error? The point must be elucidated by further experiment. Should it prove that we have here a general source of error, it is satisfactory at least that we have discovered it at the threshold as it were of our accurate experimental inquiries, and that we can devise means of avoiding it in future.

I therefore repeat the Suggestions I. and II., which I ventured to offer in page 90 (Appendix), that some of my readers, of whom I believe many are interested in this subject, would in the ensuing season ascertain accurately the produce of equal measured quantities of the same field, under whatever crop it may be, and publish or transmit the result to me—and that in all future experiments made with the view of ascertaining the effect of different manures upon any crop, *two plots at least, and not adjoining to each other*, should be treated alike in each field, and the mean of the several results obtained with each substance taken as the average produce from which their comparative effects are to be estimated.

These points appear to me to be of primary importance, and to lie at the foundation of the structure I hope we are now beginning to rear with the results of inductive experimental agriculture.

4°. *Action of soot.*—In these experiments a top-dressing of soot increased considerably the produce of oats and wheat, while it diminished the produce of potatoes *when mixed with the manure.* Thus the produce per acre on the dressed and undressed parts was—

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* *British Husbandry*, I., p. 412.

	Oats.		Wheat.		Potatoes.
Undressed ..	49 bush.	..	44 bush.	..	11 tons 16 cwt.
Dressed	55 bush.	..	54 bush.	..	11 tons 3 cwt.

The unfavourable effect upon the potato crop may probably be due to the mode in which it was applied, as in other districts it is very useful to potatoes, and gave, as we have seen, when applied alone to turnips an increase of 4 tons per acre.*

5° *Comparative action of soot and of nitrate of soda.*—The immediate effect of both these substances is to darken the colour and to increase the growth of hay and straw. In this respect the advantage is rather on the side of the nitrate, while the soot in some cases gives a little more grain. Thus the *increase of produce* per imperial acre of the three crops of hay, wheat, and oats, dressed with each of the three, was nearly as follows :—

	Hay.		Wheat.		Oats.	
					Grain.	Straw.
Soot.............	7 cwt.	..	10 bush.	..	6 bush.	6 cwt.
Nitrate of soda	9 cwt.	..	10¼ bush.	..	2¼ bush.	7 cwt.

In both cases, however, the sooted grass was lighter per bushel. Thus their comparative weights were—

			Wheat			Oats.
Sooted	..	..	58 lbs.	..	..	41 lbs.
Nitrated	..	..	62 lbs.	..	..	42¼ lbs.

Nevertheless, the advantage to the practical man is decidedly on the side of the soot, since the cost of 40 bushels of soot per acre was only 12s., while that of 1 cwt. of nitrate of soda was 25s. It is only to be regretted that soot is so variable in its constitution that firm reliance cannot be placed upon the uniformity of its effects.

6°. *Action of guano.*—In the text Part III., p. 243, I have stated the apparent conclusion to which the Erskine experiments, taken in connection with all the others I have yet met with, seem to point —that *it is more uniformly successful when applied to root than to grain crops.* The increase of oats in the present experiment did not exceed half a bushel per acre—though that of hay amounted to 14½ cwt.

7°. *Action of sulphate of soda.*—I have already noticed the effect which this salt has in *paling* the colour of the crop, even when the produce of grass or straw is increased. In regard to the grain we see in the experiment upon oats, that it reduced the crop 1¾ bushels per acre—while the wheat crop was increased 10 bushels by a similar application.

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* Mr Fleming's Experiments, Appendix, p. 67. See also, Lecture XVII. Part III., p. 201.

Is this difference in its effects due to the nature of the soil, or to the special action of the sulphate upon the two crops?

We have seen—in the experiments made in 1842 at Lennox Love,*—that the sulphate of soda diminished the *oat* crop 15¼ bushels per acre—an effect, however, which may be mainly ascribed to the great drought in that locality, since even nitrate of soda caused a diminution of 12½ bushels. But it also diminished the wheat crop at the same place to the extent of 9½ bushels per acre, but upon this crop also the drought appeared to interfere with the natural action of the several top-dressings which were applied so that no trustworthy conclusion can be drawn from the apparent results of their action.

Suggestion XII.—I have already suggested† an interesting experiment with sulphate of soda in order to test the very curious observation of Mr. Fleming, that when applied to land sown with artificial grasses, it brought up a crop consisting almost entirely of fescue grasses, though none of these had been sown. I would here suggest further that the marked difference observed at Erskine between the action of the sulphate upon wheat and oats should be further investigated—with the view of obtaining a satisfactory answer to this question—Does sulphate of soda act less favourably upon wheat than upon oats in the same soil? Or does an unlike action manifest itself only when the soils are different? I fear the suggestion comes too late for the present year, unless, as I hope, there are experiments already in progress which will throw light upon the question. But the suggestion will not, I believe, be overlooked when another year comes round.

It is further worthy of remark in regard to the action of the sulphate of soda upon the wheat crop—that the straw was stronger and less laid than where any of the other dressings were applied.

8°. *Action of Sulphate of ammonia.*—The substance employed under the name of sulphate of ammonia, as I stated in a previous part of this Appendix (p. 94), is not what its name implies. The makers, the Messrs. Turnbull of Glasgow, inform me that it is prepared by adding sulphuric acid to fermenting urine, and evaporating to dryness.‡ Though such a substance must vary in composition from the urine from which it is prepared, and must contain more or less ammonia according to the degree of fermentation which the urine has undergone—yet good effects may fairly be expected from it. I here exhibit the effect of 1 to 1½ cwt. per acre applied to different crops—

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* Appendix, p. 79.

† Suggestion IX. in Appendix, p. 109.

‡ In the text I have described it under the name of *sulphated urine.*—See Part III. p. 229.

	Undressed.	Dressed.	Made at
Wheat . . .	44 bush. . .	54½ bush. . .	Erskine.
Do., . . .	31¼ bush. . .	40 bush. . .	Gadgirth.
Oats . . .	49 bush. . .	50 bush. . .	Erskine.
Turnips. . .	12¾ tons. . .	24¼ tons. . .	Barochan.
Potatoes. . .	12¾ tons. . .	14¼ tons. . .	do.
Do. . .	8¾ tons. . .	13½ tons. . .	do.

These results not only recommended this substance to the practical farmer, but they also enforce the remarks I have made in the text upon the value of urine in general, upon the large waste of manure annually incurred by the neglect of it, and upon the virtual *money-loss* which is suffered by those who allow it to escape from their farm-yards.*

9°. *Action of Turnbull's humus.*—This humus, as it is called, is night-soil urine and mixed with charcoal and gypsum, and dried by a gentle heat. Its effects upon the wheat crop are in the present experiments, more favourable than any of those I have yet placed upon record. The following experimental results exhibit the nature of its action in two localities, both in the same neighbourhood:

	Undressed.	Dressed.	Experiment made at
Wheat . . .	44 bush. . .	51 bush. . .	Erskine.
Oats	49 bush. . .	45 bush. . .	do.
Turnips. . .	12¾ tons . .	13¾ tons . .	Barochan
Do. . . .	12 tons . .	17 tons . .	do.
Potatoes . .	5¾ tons . .	10¾ tons . .	do.

These results, especially those upon the corn crops, are not so beneficial as might well be expected from a prepared night-soil, and they afford room for the suspicion that the mode of manufacture has been such as to dissipate some of the more valuable constituents.

10°. *Experiments upon potatoes.*—In the experiments upon potatoes the whole crop averaged 12 tons per acre, and the parts of the field to which the artificial manures were added exhibited no marked increase above this general average. Even the mixture of nitrate with sulphate of soda, which in so many other cases has proved beneficial of the potato crop, in this instance produced only 1 cwt. of increase.

It may be that the manure which was added at the rate of 45 tons per acre contained a sufficient supply of all those kinds of food which were added afterwards in the saline and other substances. If so a large crop could only have been obtained by the addition of some other substance not tried, for a loam of moderate quality ought to be able to produce more than 12 tons of potatoes per acre.

* See Lecture XVIII., p. 249.

Or it may be that these same artificial manures would have produced a larger increase had they been put on as a top-dressing after the crop had come up, instead of being spread upon the manure before the potatoes were planted upon it. In the experiments of Mr. Fleming made with especial reference to this point,* it was found that *a larger proportionate increase* was obtained from the same saline substances applied in equal quantities to the potato crop *when they were spread upon the manure, than when they where applied as a top-dressing after the crop had come up*. Still the experiments in his case being made in different fields, I stated that the point was not to be considered as established, but was deserving of further investigation. This opinion is strengthened by the results of these experiments of Lord Blantyre : I would, therefore, beg to offer as

Suggestion XIII.—That the application of saline manures to the potato crop—either when the trial is made for the purpose of obtaining practical information, which may, hereafter, be valuable as a guide to the operations of the farmer, on the land where his experiments are made, or for that of arriving at results which may be theoretically useful—that the same proportions should be applied to two or more plots buried with the manure, and to two or more dusted on as a top-dressing. From an accumulation of results obtained in both ways, we shall be able to extract something like a principle by which practical men may be easily guided in that direction which is likely in the greatest number of cases to lead to the greatest amount of profit.

11°. *Water in the potatoes.*—I will here add one other observation upon the potato experiments. There was, as we have already remarked, no notable difference in the *weight* of crop raised upon the several patches. But the *quality* of the crop—the weight of dry food raised upon the several patches—might really be different notwithstanding. In my remarks† upon the Barochan experiments upon potatoes, made in 1842, I have drawn attention to the fact that potatoes sometimes contain as much as 30 per cent. of dry food, and at other times as little as 20 per cent., and therefore that a ton of potatoes of one kind may contain 6 cwt., while the same weight of another contains only 4 cwt. of dry nourishment. It may be, therefore, that as by growing in unlike soils or with unequal degrees of rapidity our potatoes may contain different proportions of water, so by different kinds of dressings which act in the same way as natural differences of soil, and cause the plants to develope themselves with greater or less rapidity, the same effects may be produced. One kind of saline substance, such as nitrate of soda, by hastening the growth, may give us a crop of potatoes containing much water, while another, such as sulphate of soda, by retarding the growth, may give a crop containing less water—and thus though there may be no difference in the weight of the two crops, they may be very unlike in the relative proportions of food they contain.

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* Appendix, pp. 74, 75 and 100.

† Ibid, p. 98.

If such be the case it is of great practical importance to determine the quantity of water which our several experimental potato crops contain, since without this we may draw very incorrect conclusions as to the value of our experimental manures—placing the highest value upon that which gives the greatest weight of raw material, and esteeming least, perhaps, that which produces the greatest weight of dry food.

I would again, therefore, draw the attention of my readers to the subject of Suggestions IV. and VI.,* in reference to the determination of the quantity of water in their experimental root crops. The method of doing this is very simple, and has already been described.†

Each new series of experimental results we are called upon to examine and analyze will, I hope, more and more satisfy my readers, as they do myself, that this is the true line of procedure, and that though there may be much in our results at first which may appear contradictory and discouraging, yet that out of these crude results, when combined, compared, and frequently repeated, the real substance of a rational agriculture will, slowly it may be and with difficulty, yet surely at last be extracted.

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* Appendix p. 96, and 100.

† Appendix, p. 97.

Eratum.—Page 77, dele *not* in line 19 from bottom, and read *not on the alert*, in the 18th line.

JAN 27 1883

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